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FINAL REPORT

THE ROLE OF BOAT WAKES IN SHORE EROSION

In Anne Arundel County, Maryland

Dept of Natural Resources

FINAL REPORT ON THE ROLE OF BOAT WAKES IN SHORE EROSION IN ANNE ARUNDEL COUNTY, MARYLAND

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EDITORS' NOTE

The environmental impacts caused by motorboats have been the subject of several recent studies. Much of the technical information which has been amassed so far deals with the effects of two-cycle outboard motorboat engines on water quality and the health of aquatic organisms (Jackivicz, et. al. 1973). A few studies have shown there are short-term changes in turbidity and other water parameters while boats are operating, but the effects are very temporary (Yousef, 1974, et. al., 1978; Anderson, 1976; Moss, 1977; Liou and Herbich, 1977). None of the studies have concluded that these short-lived environmental impacts are actually detrimental to the ecology of isolated lakes or small creeks and coves where boats operate.

There have also been several recent studies on the impacts of boat wakes, but most of the attention has been directed to the wake characteristics of large commercial ships, barges, and tugboats. Information has been gathered to address some suspected environmental problems where boat wakes travel out of shipping lanes onto recreational beaches, and where wakes wash against levees in restricted channels and canals (Hay, 1968; Das, 1969; Johnson, 1969; Collins, et al, 1971). The technical studies show how different types of passes by these large-hulled craft can produce different wakes along the shoreline (Brebner, et. al., 1966; Johnson, 1957, 1968, 1969; Sorensen, 1967a, b, 1973; Das and Johnson, 1970).

This document describes a study of the role of wakes from smaller boats in causing erosion along the shoreline in areas which are relatively sheltered from natural wind-generated waves. The Severn and South Rivers are two tributaries to the Chesapeake Bay near Annapolis which are popular for recreational boating, along with the smaller creeks and coves adjacent to the main river channels. The information which was collected as part of this study was used to answer some important questions about the relationship between recreational motorboating and shoreline erosion in these areas:

1. What levels of wave energy are associated with boat wakes in particularly popular areas, and how do the wakes compare with the normal wind-generated waves as a source of energy for erosion and transport at the shoreline?

2. Can different types of boating patterns change the levels of wave energy in boat wakes which break along the shoreline?

3. How do rates of shore erosion during the boating season compare to other times of the year?

This study report describes measurements of boat wakes, wind waves, and shoreline surveys collected over a one-year period which included a single boating season and a single winter storm season. Thus, the length of time over which the data base extends is limited, and the results are strictly applicable only to the shorelines at the study sites. Nevertheless, the limited data set and associated analysis provide preliminary answers to the questions above which will be useful to scientists, managers, decision-makers, and other persons who participate with interest in public forums and related discussions where recreational motorboating is regarded as a significant management issue.

Chris Zabawa
Chris Ostrom
December 1, 1980

EXECUTIVE SUMMARY

In 1976, the Maryland General Assembly passed a resolution requesting that DNR design and undertake a study to determine whether recreational motorboat traffic is detrimental to the ecology of small creeks and coves in Anne Arundel County. The data which are described in this report were collected at five popular areas for motorboating to assess the effects of boat wakes on shore erosion. Over a one-year period, wave energy in boat wakes at each site was compared with the energy in wind waves to show the increased potential for shore erosion due to boats. Erosion rates during the boating season were also compared to other times of the year at each of the study sites. Finally, wakes were measured from controlled boat passes to determine the importance of different boat speeds and distances from the shore in producing different-sized wakes.

Except at one site, the most important contribution to shore erosion during the year of study was Tropical Storm David, which passed through Maryland in September, 1979, and was accompanied by the greatest changes in some of the shoreline profiles. Wind waves ranked behind the storm effects; and in all cases, boat wakes contributed less energy for erosion than wind waves.

Only one of the study sites showed evidence of erosion during the boating season. This site also had the highest levels of wave energy from boat wakes, even though some of the other sites had higher amounts of boat traffic. But the boats passed particularly close to the shoreline at the site where erosion occurred during the boating season; consequently, the wake energy did not dissipate before reaching the beach. Thus, the distance to which boats approach the shore is a very important factor for evaluating erosion due to boat wakes.

Two other important factors for evaluating erosion in small creeks and coves are the physical nature of the sediments, and the appearance of the shoreline profiles. The sites used in this study possessed physical characteristics which are representative of many other shoreline locations in Anne Arundel County, and the report discusses the particular characteristics at each site which were important to the erosion process.

Other factors were also studied because they affect the heights of waves, and thus the energy, in boat wakes. Besides distance from shore, the energy in boat wakes varied with different boat speeds, and with different depths of water. For the range of water depths in small creeks and

coves of Anne Arundel County, the largest wakes can be expected from boats travelling slightly faster than the six-knot speed limit which is posted in many places. This increases the potential for erosion due to boat wakes in areas where boats reduce their speeds to conform to posted speed limits, as well as in areas where boats exceed the posted speed limit by only a small amount (1-2 knots).

Chapter VIII of this report contains a table of calculations for estimating those boat speeds which will generate maximum wakes in creeks and coves with different water depths. These ranges of boat speeds are suitable for use in a review of existing State policy to suggest changes in boating speed limits based on both safety and environmental reasons; but, this study shows that other environmental factors also need to be considered, especially the physical nature of the shoreline in any particular area, and the distance away from shore which motorboats pass.

I

INTRODUCTION

Chris Zabawa, Chris Ostrom,
Robert J. Byrne, John D. Boon III
Rhonda Waller, and Deborah Blades

A. Purpose of the Study

Since the close of World War II, the population in the counties fringing the Chesapeake Bay estuary in Maryland has increased dramatically, particularly on the western shore. Along with this population increase, recreational boating activity on the waterways has also increased substantially. For example, between 1968 and 1973, the number of pleasure boats registered in the State of Maryland grew at an annual rate of about 5% (from about 62,000 boats registered in 1968 to over 76,000 in 1973) (Roy Mann Associates, 1974). Approximately 40% of this increase in registered boats was concentrated in Anne Arundel, Baltimore, Harford, Cecil, Kent, Queen Annes, and Talbot counties.

There has been increasing concern that the wakes generated in some of these areas due to the heavier boat traffic may be accelerating rates of shore erosion, particularly in the smaller creeks and coves. In 1976, the Maryland General Assembly passed a resolution requesting the Department of Natural Resources to undertake a study to evaluate whether recreational motorboat traffic is detrimental to the ecology of small creeks and coves in Anne Arundel County, Maryland (Appendix A).

Potential impacts from motorboats in small creeks and coves could include effects on the turbidity and mixing of the water, toxic effects of oil and gas emissions from boat engines, damage to aquatic vegetation, and increased shore erosion due to boat wakes. In response to the General Assembly resolution, DNR conducted a literature search of previous boating studies with the cooperation of Federal agencies, and assessed the implications of existing technical information for small creeks and coves in Anne Arundel County. There were few pertinent studies found, and none concluded that boating impacts were actually detrimental to the ecology. The Environmental Protection Agency is presently engaged in further studies of some potential boating impacts in the South River (Williams and Skove, 1980). Several years' worth of data are required in many of these studies to obtain an understanding of cause and effect, since the variability of environmental factors can be fairly large from year to year.

On the other hand, a one year study of boat-wake energy and shore erosion can provide an indication of the potential seriousness of the problem for sites similar to those selected in Anne Arundel County. Therefore, in response to the General Assembly Resolution, the Department of Natural Resources elected to conduct a study to evaluate the contribution of boat-wake energy to the erosion of the shoreline fringes of small creeks and coves.

B. Contents of this Report

This report describes the collection and analysis of data from five shoreline sites to test three hypotheses:

1. Boat-wake energy is a substantial contributor to the overall wave-energy budget at the study sites.

2. Erosion of the shoreline sites is higher during the boating season than at other times of the year.

3. Different boat designs and passage characteristics can change the levels of wave energy in boat wakes.

To test the first two hypotheses, measurements of boat wakes were collected during the summer of 1979, and measurements of wind waves were collected at all times of the year between October 1978 and October 1979. In addition, shoreline surveys at the study sites were collected on a monthly basis between October 1978 and October 1979. The study sites constituted a representative cross-section of shoreline types (including beach, marsh, and bluff) in Anne Arundel County. The principal sites and shoreline surveys are described in Chapter IV of this report. Some alternative sites were chosen to be used by the consultants in case the boating patterns at the original five selected sites were not as anticipated. Chapter V contains descriptions of these additional sites.

TABLE 1.1

Site	Location[1]	Average Boat-Passes Per Day[2] WD = Weekday WE = Weekend	Yearly Wave Energy Budgets[3] Wave Energy ($ft\text{-}lbs/ft^2$) Wind Wave	Boat Wake	Yearly% Boat-Wake Energy	% of Wave Energy in Wakes in Boating Season
A	Vegetated sand spit on Lower South River at Harness Creek	170.5 (WD) 735.7 (WE)	5,450,816	118,100	2.2%	4.4%
B	Steep bank on Upper South River near Goose Island	91.9 (WD) 344.2 (WE)	4.133,173	70,680	1.7%	3.6%
C	Marshy promontory on Broad Creek	95.2 (WD) 326.2 (WE)	3,823,991	376,040	9.6%	20.4%
D	Bluff on lower Severn River at Severnside	155.8 (WD) 268.8 (WE)	6,969,310	247,660	3.6%	8.4%
E	Pocket marsh in Maynedier Creek	44.6 (WD) 69.8 (WE)	3,181,249	15,650	0.5%	0.9%

1. From Chapter IV.
2. From Chapter VI.
3. From Chapter VII and Appendix B.

Boating patterns at each of the five principal sites during the summer of 1979 are described in Chapter VI. The wind-wave measurements are contained in Appendix B, and the wind-wave energies are compared to boat wakes in Chapter VII.

To test the third hypothesis listed above, trial runs of boats with two different hull designs were conducted at one shoreline site, and the wakes from different boat passes were compared for boat passes at different speeds and distances from the shoreline. These data are described and analyzed in Chapter VIII.

C. The Results

Table 1.1 (opposite) summarizes the boating frequencies and wave-energy budgets which were collected for the study. At four of the study sites, there was no increase in shore erosion which could be attributed to boating during the summer. The most important contribution to shore erosion was Tropical Storm David, which passed through Maryland in early September 1979, and was accompanied by the largest erosion in some of the shoreline surveys. Wind waves rank behind the storm effects in causing the observed shoreline changes over the year of observations, and in all cases boat wakes represented lower levels of wave energy. It is important to note that these results are drawn from a one-year data base and do not incorporate any variability which might be detected over a longer period of data collection.

At one site (Site C) there was considerable erosion of the fastland during the summer of 1979. The boat-wake energy at Site C is an important factor responsible for the erosion, but the physical shoreline setting could also be important. Since Site C is located at a narrow point on a creek, the boats pass particularly close to shore relative to the other sites, and wake energy does not dissipate before reaching the beach. Thus this site experienced the highest boat-wake energy during the summer of 1979, even though some of the other sites had higher frequencies of boat passes.

The results of the experiment with controlled boat passes show different types of boats, and different modes of operation of the same boat, can produce measurable changes in the wave energy contained in boat wakes. For the types of boats tested, maximum boat-wake energy occurred when the boat speed was about 8 knots; a high-speed passage (20 knots) produced lower wake energy. The water depth in this case was approximately 12 feet. For different water depths, maximum wake energy can occur at different speeds since the wave energy varies with both the speed of the boat and the water depth. In water depths of 6 feet or less, maximum or near-maximum wake energies can occur at boat speeds closer to 6 knots.

D. The Conclusions

One conclusion about boat wakes is the largest contribution to the total wave energy (and thus to the total potential for shore erosion) from wakes can be anticipated where there is a high frequency of boat passes close to a particular shoreline site. The actual level of fastland retreat in response to recreational boating patterns at any particular site will also depend upon the nearshore change in slope on the shoreline profile, upon the composition of the fastland, and upon the supply of sediment carried onto the shoreline site from alongshore.

The type of shoreline most susceptible to erosion would have a combination of:

- o exposed point of land in a narrow creek or cove;
- o fastland consisting of easily-erodable material such as sand or gravel;
- o steep nearshore gradient on the shoreline profile;
- o location adjacent to a high rate of boating, with boat passes relatively close to the shoreline.

The site which experienced the most fastland erosion during the boating season (Site C) had all four of the above characteristics.

Three more conclusions about wakes can be drawn from this one-year study for the range of basin depths frequently encountered in narrow creeks and coves in Anne Arundel County:

1. As boats reduce their speeds to conform to posted speed limits, they pass through a speed range in which the hull generates a maximum wake.

2. If the approach to a posted speed-control area is within a narrow creek, then the shores adjacent to the speed-reduction zone will be exposed to the high wake energies.

3. Boat operators can unknowingly generate a near-maximum wake while they are transiting a waterway if they misestimate their speed by only a few knots while their boat is in a posted speed-control zone.

E. Thoughts for Managers

1. The data collected for this study show that depth conditions are suitable at some shoreline sites in Anne Arundel County for maximum boat-wake energies to be generated from boats passing a posted 6-knot (or 6.9 mph) speed-limit zone. One of the products of this study is Table 8.3 in Chapter VIII which can be used to estimate the speeds at which maximum wakes would be generated in different areas which have different water depths. In some cases, posting a lower speed limit would decrease the wave heights in wakes which break on the shoreline.

2. Since boats which are slowing to approach a posted speed-control zone will pass through the range of

speeds which generate maximum wake, speed-limit signs should be posted, when possible, in portions of creeks which are so wide that wake energies will substantially dissipate before reaching the shoreline.

3. The data collected for this study indicate that the greatest potential for boating to increase erosion rates above natural levels can be expected when high frequencies of boat passes occur within a few hundred feet from the shore.

F. Suggested Future Studies

Further studies at other sites in Anne Arundel County are not likely to show boat wakes contribute more wave energy than wind waves for shore erosion. In the one-year period of observations, narrow waterways where boats passed closed to the shore held the greatest potential for increased erosion due to boat wakes. Further studies over a period of 4 to 5 years might show this potential is highly variable depending on boat traffic and boating patterns.

At Site C, about 80% of the boat traffic occurred at distances of 200 feet or less from the shore; in contrast, Site B had about 75% of the boat passes at distances greater than 500 feet. As a result, the wave energy due to boats at Site B was only about 20% of that experienced at the Broad Creek site. So boat passes between 200-500 feet from shore can appreciably reduce the level of wave energy in wakes which break along the shoreline. Further observations of controlled boat passes over a wider range of distances at selected shoreline sites would permit a more accurate determination to be made of the critical creek width which is needed to produce negligible wake energy along the shoreline. The controlled boat passes which were conducted for the study described in this report covered the range of distances from 50 to 200 feet offshore at a single shoreline site. This range of controlled boat passes should be extended to at least 500 feet from the shore. In addition, other areas with different beach and nearshore profiles could be selected for measuring wakes from controlled boat passes, and boats with different hull designs could be tested.

II
THE EROSION PROCESS

Robert J. Byrne, John D. Boon III
Rhonda Waller, and Deborah Blades

Shoreline erosion is defined here as the loss of subaerial fastland to the aqueous environment; it is <u>not</u> necessarily reflected in short-term changes in the beach which can be measured by surveying the shoreline over periods of a few weeks or months.

As an example, consider a shoreline segment where the "fastland" is a bluff (Figure 2.1). In the geologic setting of Anne Arundel County, there is generally a narrow sand beach at the base of the bluff shorelines. Excavation of this sand beach would disclose that the sand layer was relatively thin, and that within a few feet below the beach surface the consolidated bluff sediments would again be encountered. Observations of shoreline profiles at such a site throughout the course of a year would quite possibly show that the width and depth of the sand lens on this beach varied, while the portion of the shoreline profile on the bluff face remained unchanged.

This beach is a natural feature which is formed and reshaped by the action of breaking waves throughout the nearshore and particularly in the swash zone, where the undulatory wave motion is transformed into turbulent uprush and backwash on the beach slope. Once beaches are formed by wave erosion of the fastland sediments, the beach sediments

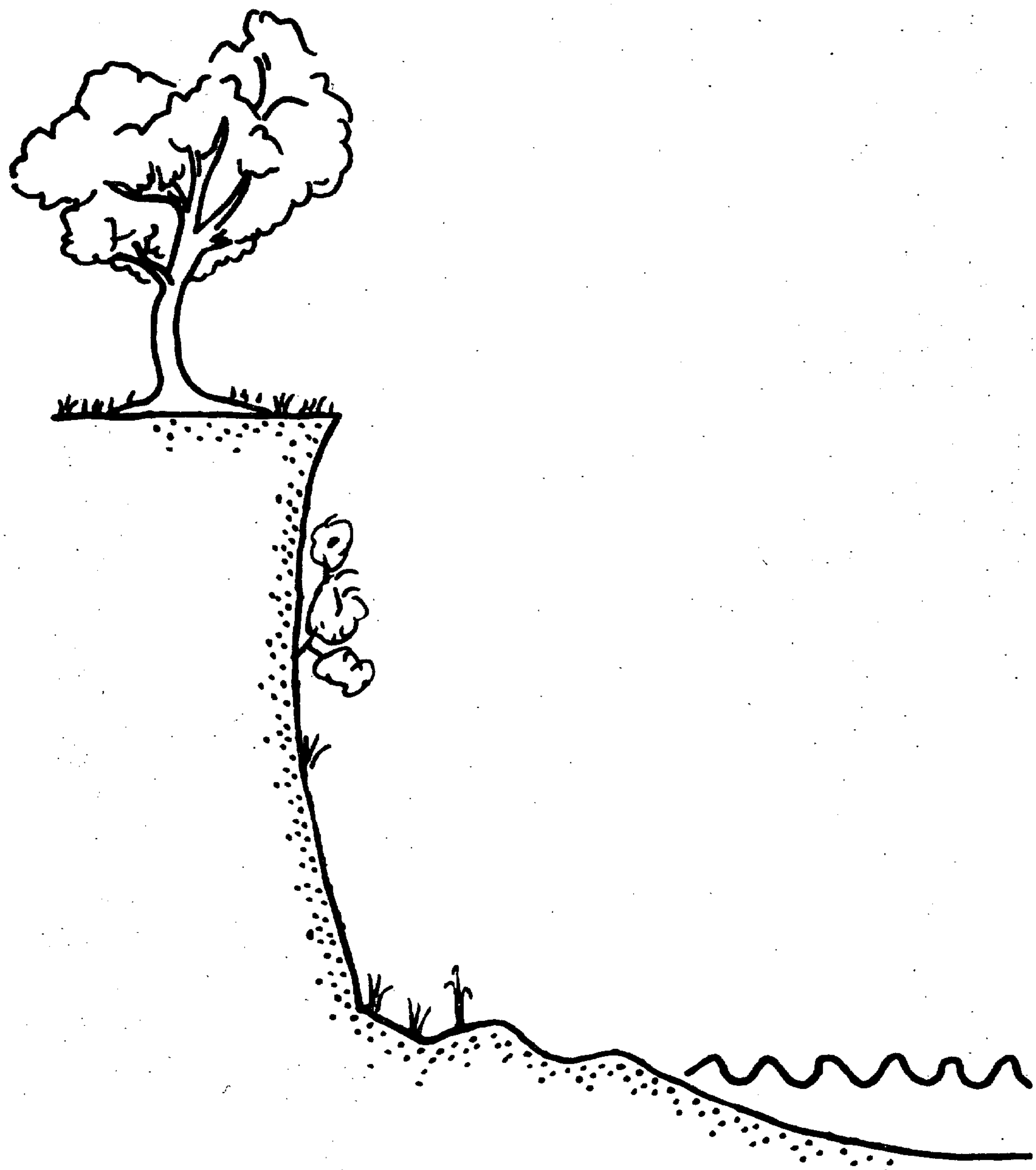

Figure 2.1

are in turn the most effective natural absorber of wave energy along the shoreline. The volume of sand on the beach at any given time depends upon wave conditions and water elevations over the previous several days. Since the beach profile is so affected by short-term wave events, the condition of a single beach profile is itself not a reliable indicator of erosion. However the retreat of the fastland, which can also be measured on shoreline profiles through time, is an unambiguous indicator.

The chief agents of fastland erosion are wave action against the shoreline and the elevation of the water surface both during the normal tidal cycle and during severe storms. Tidal currents in certain circumstances may also exert a significant control on shoreline stability. Finally, surface rain runoff and groundwater seepage may play a particularly important role in eroding steep bluffs and banks (Palmer, 1973). During periods of active rainfall or snow melt, surface runoff may trickle down the steep slopes of bluffs or banks, and incise small channels in the exposed sediments. A more serious impact on erosion is probably due to the percolation of rainwater into the sediments which form the bluffs or steep embankments. This seepage can subsequently discharge from the face of an embankment and cause instability and slumping.

In those bluffs containing impermeable layers, the groundwater discharge can be more concentrated where the

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opposite: Figure 2.1 Schematic drawing of a beach at the base of a bluff.

upper surface of the impermeable layer is exposed. This surface then becomes a slide plane offering little support to the sediments above the layer. Over the long-term, the slumping of these sediments will form a talus deposit at the base of the bluff, and the overall gradient of the exposed bluff face will decrease. Vegetation may also grow on the bluff face and stabilize the eroding sediments. However, with the presence of significant wave action, the talus material at the toe of the bluff is transported away from the site, leaving the embankment in an oversteepened configuration once again.

In regions of the Chesapeake Bay basin where wave energy for shore erosion is generated by local winds, the levels of wave energy are dependent upon the open water distance over which the wind blows (fetch), the duration of the wind, and most importantly on the wind speed. However, the changes which are produced in the shoreline profile at any site due to wave energy are dependent upon the level of the water surface on the profile.

Several factors control this level of the water surface, and thus control the zone of application of breaking waves on shorelines. Besides the "normal" semi-diurnal tidal excursion of about 1 foot in the small creeks and coves of Anne Arundel County, the long-term fluctuation in sea level is an additional factor which influences the level of the water on shoreline profiles. Due to the melting of the polar ice caps over recent geologic time, mean sea level has risen to its present location over the past few thousand years. Within the Chesapeake Bay region the relative sea-level rise is presently about 1 foot per century. At Annapolis, the sea level has risen at least 4 inches since 1929, when tide gauge records first began to be collected (Hicks, 1972) (Figure 2.2). While this rate of sea-level rise is slow, it is sufficient to drown low-lying lands and to maintain a continual landward encroachment of the zone of application of wave energy by natural forces on any shoreline profile.

Short-term sea-level variations due to large-scale atmospheric events also play a strong role in determining where waves will erode sediments on shoreline profiles. With the onset and duration of a regional northeast storm, variations in regional atmospheric pressure cause additional water to be forced into some portions of the Chesapeake Bay basin. This results in a super-elevation of the mean tide level, or storm surge, which may overtop a beach in some areas and allow the waves to expend their energy directly against the fastland. Storm surge elevations of two to three feet above expected tide level are not uncommon during northeasters in Chesapeake Bay. As a storm center passes through the Bay region, the easterly winds shift to the north and northwest and frequently become stronger and of longer duration. This may increase the wind-generated wave heights but it also relaxes the storm tidal surge in the vicinity of Anne Arundel County as the water level in the rivers fringing the western side of the Bay is then depressed below normal. Under these circumstances, the wave energy is dissipated along the lower portions of the shoreline profiles on the foreshore of the beach or in the nearshore zone, and the fastland is relatively immune to direct wave attack.

Even in the absence of major northeasters, several other factors combine to produce a measurable variation in mean tide level throughout the year. These include an annual variation in oceanic water temperature, and normal seasonal differences in regional atmospheric pressure.

At Annapolis, the monthly variation in sea level due to all factors is such that between April and October the mean tidal level is higher than between November and March (Figure 2.3). The range in the annual elevation of mean tide level is about equal to the tide range. The importance of this phenomenon is that the zone of application of wave energy is generally at higher elevations on the shoreline profile during the recreational boating season, with the maximum elevations being attained in August and September.

<u>opposite</u>: <u>Figure 2.2</u> (top) Changes in values for yearly mean sea level at Annapolis, Md. (after Hicks, 1972).

<u>Figure 2.3</u> (bottom) Monthly variation in mean sea level at Annapolis (after Boon, 1978).

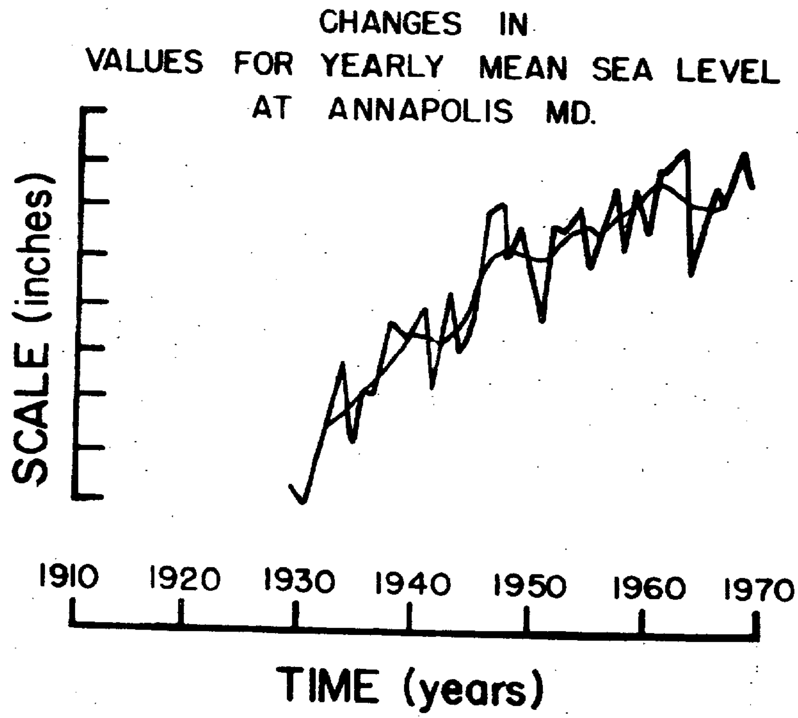

Figure 2.2

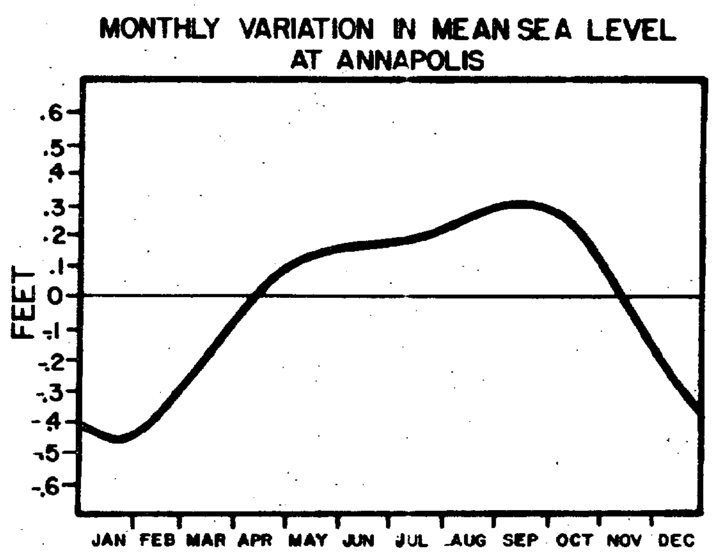

Figure 2.3

III
SAMPLING STRATEGY AND SITE SELECTION

Chris Zabawa, Chris Ostrom, and Mark Alderson

A. Sampling Strategy

To study the effects of boat wakes on the erosion process which was discussed in the previous chapter, measurements of shoreline changes were collected over a year at some selected sites in Anne Arundel County. Changes in the beach and fastland in the time between surveys can be discussed in terms of the wind-generated waves which dissipated their energy on the shoreline all year, and in terms of the boat wakes which are concentrated during the summer months. The sites were selected principally because they were in popular areas for boating and water skiing, but they also are respresentative types of shorelines which occur in Anne Arundel County, including beach, marsh, and bluff. Some effort was made to obtain sites which received wind waves from different directions and fetches.

B. Site Selection

The site selection process involved the following steps:

1) Areas of intense boating activity were identified by several groups, including:

   a. Magothy, Severn, and South River Associations;
   b. Anne Arundel County Boating Advisory Committee;
   c. Anne Arundel County Planning and Zoning Office;
   d. Maryland DNR Marine Police.

2) Once areas of intense boating activity were identified, potential shoreline sites were identified from aerial photographs which accompany the county tax assessment maps;

3) Letters were sent to approximately 120 landowners explaining the purpose of the study and requesting permission to make a site visit;

4) Visits were made by a DNR team to approximately 84 sites whose owners had no objection to participating in the study. Sites were disqualified if the owner indicated that he had applied for a permit for erosion control structures, or was planning to install shoreline structures within the forthcoming year. Owners were also asked whether they felt their land was located adjacent to an area of high boating activity. During the site visit, other observations were made, including:

   a. shoreline and beach morphology:
   b. shoreline sediment type;
   c. evidence of erosion;
   d. proximity of shoreline structures;
   e. orientation into the wind and approximate fetch;

5) 15 candidate sites were identified from the site visits. From these, five sites were selected for study by geologists from Coastal Resources Division of DNR and Maryland Geological Survey, together with the consultants.

The locations of these five sites are shown in Figure 3.1. The sites which were selected include:

Site A. A vegetated sand spit on the lower South River, at the entrance to Harness Creek.

Site B. A steep bank on the upper South River, near Goose Island.

Site C. A broad, marshy promontory on Broad Creek off the upper South River.

Site D. A bluff on the lower Severn River at Severnside.

Site E. A pocket marsh near the entrance of Mayneider Creek, off the upper Severn River.

The sites were chosen as being representative of varying physiographic conditions with respect to bank elevation, sediment composition, nearshore bottom gradient, and exposure to wind-wave activity.

Chapter IV contains a description of the shoreline profiles which were collected at these sites by the consultants on a monthly basis from October 1978 through October 1979. Chapters VI and VII describe the boating frequencies which were measured at these sites during the summer of 1979, and the boat-wake energy levels. Appendix B describes the wind-generated waves which were measured at these sites during the year of study.

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opposite: Figure 3.1 Location map of the consultants' study sites in Anne Arundel County.

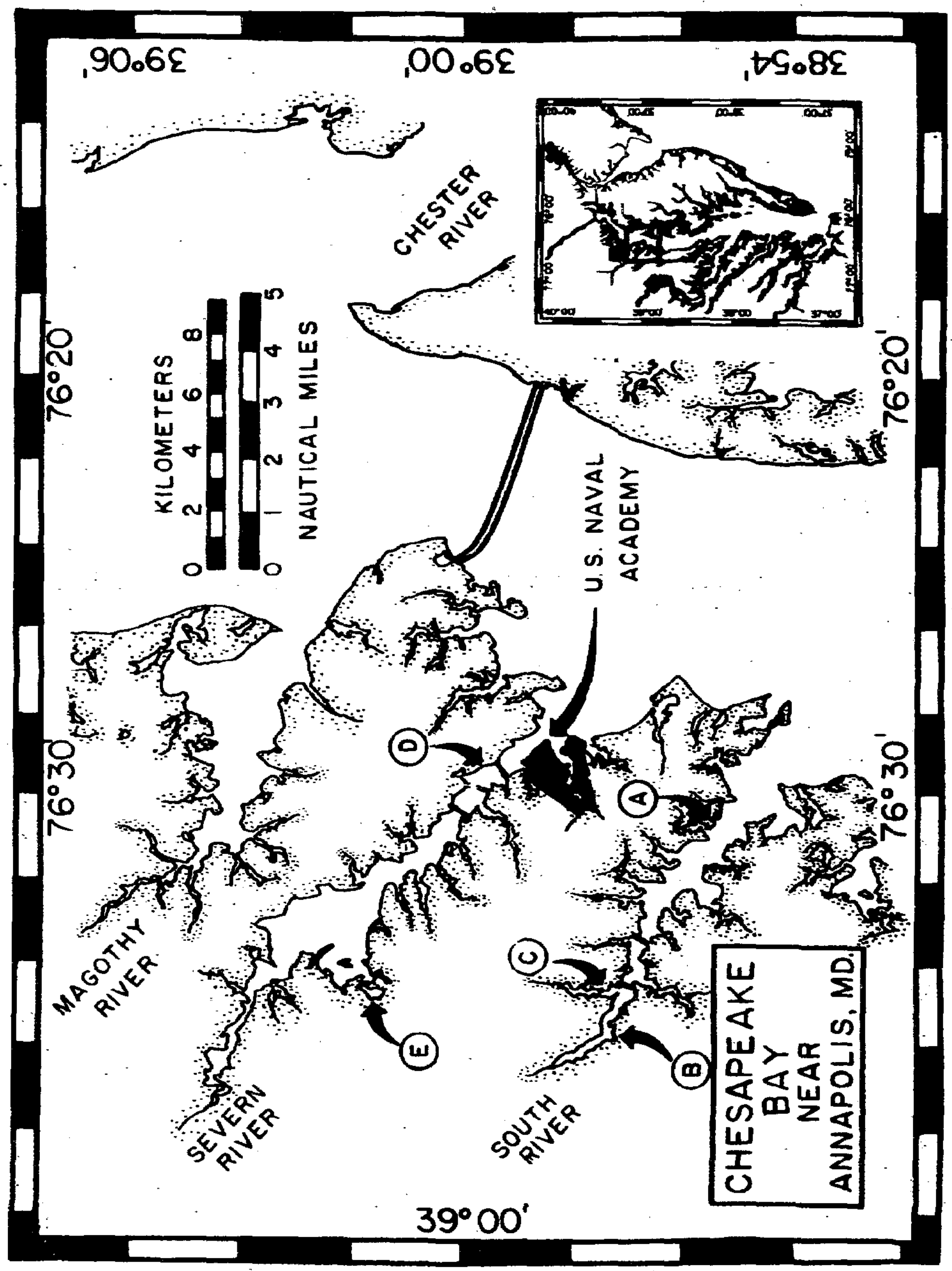
CHESAPEAKE BAY NEAR ANNAPOLIS, MD.
CHESTER RIVER
MAGOTHY RIVER
SEVERN RIVER
SOUTH RIVER
U.S. NAVAL ACADEMY
KILOMETERS
0 2 4 6 8
NAUTICAL MILES
0 1 2 3 4 5
A
B
C
D
E
39°06'
39°00'
38°54'
76°20'
76°30'
39°00'

Figure 3.1

At the beginning of the study period, two additional sites were selected by students participating in a DNR co-operative work-study program at the Anne Arundel Community College. One site (AA) was located along a bluff and adjacent pocket marsh inside Harness Creek, in the vicinity of the consultants' site A. Another site (FF) was located along a beach and sandy marsh at Beard's Point on the upper South River. These sites were regarded as "back-up" sites to be used by the consultants in the case that boating patterns at one of the initial sites A-E were less intense than expected. The AA Community College students also monitored shoreline changes directly adjacent to two of the consultants' sites in areas where a different type of shoreline (marsh and bank) was immediately adjacent to the principal study area. The description of these additional sites prepared by the students is contained in Chapter V.

IV

OBSERVED CHANGES IN THE SHORELINE PROFILES FROM OCTOBER 1978 TO OCTOBER 1979

Robert J. Byrne, John D. Boon III,
Rhonda Waller, and Deborah Blades

A. Introduction

The five study sites listed in the previous chapter were surveyed on a monthly basis for a one-year period to determine whether there were marked differences in the rate of fastland retreat during the recreational boating season and during other times of the year. The results presented in this chapter show few effects are able to be attributed to the recreational boating activity in a single season. The greatest changes were noted after the passage of Tropical Storm David, which occurred on September 5-6, 1979. Other changes in the surveyed profiles were also measured through the year at three of the sites. But only one site showed any important change in the shoreline profile during the boating season.

These shoreline sites could be resurveyed on a continuing seasonal basis with the landowners' continued permission to see whether trends appear in the profiles during successive seasons when boats, wind-waves, and other factors affect the erosion and transport of sediments.

B. Methods

At each of the sites, three profiling locations were selected with a separation distance of 30 feet. Each profile was established by inserting two reference pipes or stakes several feet apart on a line perpendicular to the beach or shoreline. The position of the six reference pipes was then surveyed with a transit and rod from a fixed bronze survey marker set in concrete.

When the shoreline profiles were surveyed each month, the ground elevations along each profile were referenced to that of the benchmark using a precision level and rod. The rear reference pipe was considered to be the origin for each profile. The ground elevations were surveyed at 3-foot intervals, and at all additional intermediate points where a slope change occurred. At the two sites with bluffs (Sites B and D) the profiles were extended up the bluff face from the rear stakes, and elevations were surveyed at intervals up to the instrument height.

In order to test the precision of the profiling technique, replications were made at Sites A and B (Figures 4.1, 4.2). Site A was replicated on 11/25/78 with a mean deviation of 0.020 ft. The maximum deviation was 0.075 ft. at the step of the foreshore. This difference could represent a real change in the position and elevation of the step since about one hour elapsed between successive profiles.

<u>opposite</u>: <u>Figure 4.1</u> (top) Plot of duplicate surveys at Site A on 11/25/78.

<u>Figure 4.2</u> (bottom) Plot of duplicate surveys at Site B on 11/4/78.

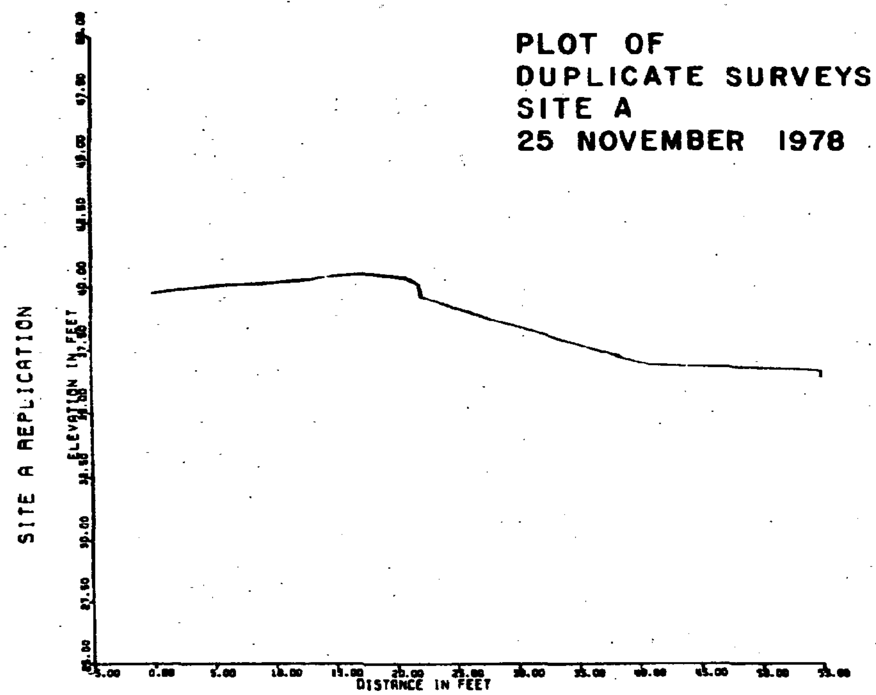

Figure 4.1

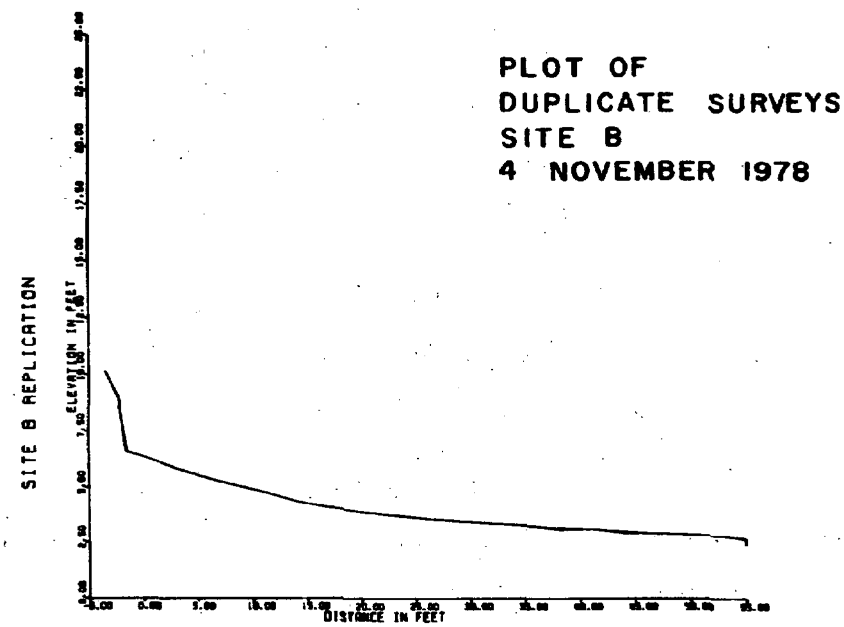

Figure 4.2

The maximum deviation outside of the step zone was 0.052 ft. The comparative plot is shown in Figure 4.1. Site B was replicated on 11/4/78 with a mean deviation of 0.016 ft. The maximum deviation was 0.069 ft. which occurred in the nearshore zone. The mean deviation of elevation within the bluff and beach zone was 0.003 ft. with a maximum deviation of 0.005 ft. The comparative plot is shown in Figure 4.2 The replications indicate that the profiling method is precise enough to discriminate changes in elevation as small as 0.1 foot. The dates when profiles were acquired at all the study sites are shown in Table 4.1.

C. Results

For the year-long period of observations, fastland retreat was measured at three sites (B.C.D). There were changes in the shoreline profile amounting to a reduction in the amount of slumped material at the toe of the bluffs at sites B and D. At site D, some bluff retreat was also measured after Tropical Storm David in early September, 1979. Only at Site C on Broad Creek did significant fastland retreat occur during the boating season.

At all the sites except Site E, there were variations measured in the beach elevations on the shoreline profiles from month to month. These variations were largely restricted to the intertidal zone. Only at

TABLE 4.1

DATES OF PROFILES

Month	SITE A	B	C	D	E
Oct, 1978	29	-	29	29	29
Nov	25	24	25	26	26
Dec	20	20	20	21	21
Jan, 1979	-	-	-	-	-
Feb	3	3	3	3	4
Mar	10	11	10	10	11
Apr	16	16	16	17	17
May	25	26	26	25	26
June	23	23	23	24	24
July	28	28	29	29	29
Aug	-	18	18	18	18
Sep	15	15	15	16	16
Oct, 1979	20	20	20	21	21

Site D was there any significant change in bottom elevations at points seaward of the low-tide line. A detailed description of the shore zone response to boat wakes and wind waves at each site follows.

SITE DESCRIPTIONS

Site A. A vegetated sand spit on the lower South River, at the entrance to Harness Creek

This site is located in the region known as Hillsmere Shores (Figures 4.3, 4.4, 4.5). The beach segment chosen for monitoring is located on a spit which trends north-south along the shoreline. The sediments which form the spit were derived from erosion of an adjacent bluff which forms a headland slightly downstream on the South River. This headland bluff is about 30 feet in elevation, and is composed of interbedded sand, silt and clay deposits of the Talbot Formation (Pleistocene Age), with a thin lower horizon of pebbly sand and gravel exposed (Glaser, 1976).

The spit begins about 500 feet upstream from the zone of active bluff erosion, and is connected to the bluff by a sandy terrace of approximately 3 feet elevation which broadens from the base of the bluff to a width of about 30 feet upstream at the point of spit attachment. This sandy terrace is also experiencing retreat due to frontal erosion along the South River shoreline. The entire portion of the South River shoreline near the spit is littered with fallen trees.

The mean tide range in the area is approximately 1.0 foot, and there were no shoreline structures present along the reach during the period of study.

The spit itself is about 400 feet in length, and the distal end exhibits a strong recurve. Earlier episodes of sand transport and deposition along the spit have led to the formation of a lagoon on the back side of the spit, and subsequent marsh growth has separated this lagoon from Harness Creek. Downstream from the study site on the spit, there is a frontal scarp which is evidence of active erosion. At the top of this scarp, the ground surface slopes towards the land instead of the water (Figure 4.5); this suggests that erosion and shoreline recession in this portion of the shoreline have already devoured the "spine" of the spit, which was the crest of the earlier natural beach or berm line formed when the spit was growing. Older marsh sediments are exposed on this scarp near the point of spit attachment to the adjacent bluff, and a shell bed up to

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next pages: Figure 4.3 (left) Location map showing Site A.

Figure 4.4 (upper right) Aerial view of Site A.

Figure 4.5 (lower right) Typical profile of Site A in October 1978.

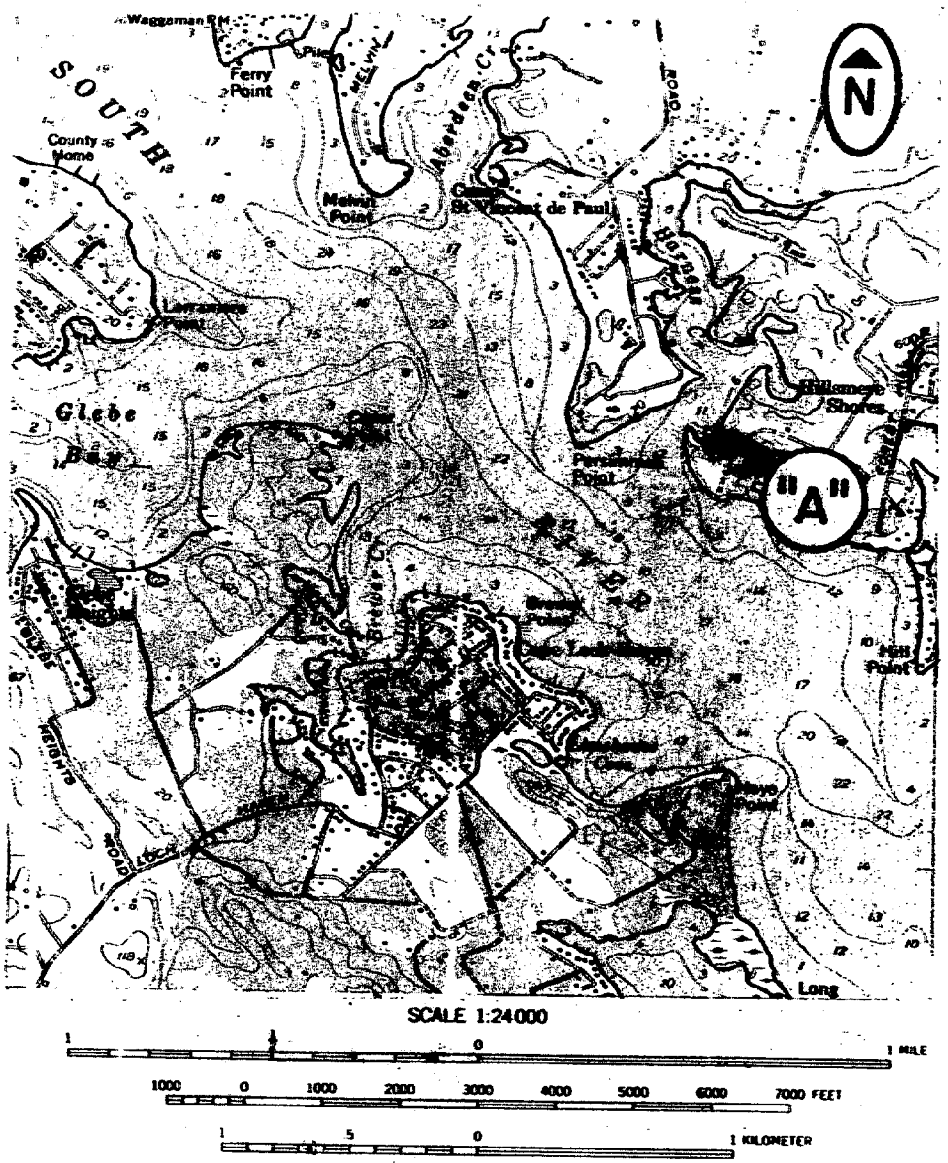
N
SOUTH
Ferry Point
County Home
Melvin Point
Aberdeen Cr.
St. Vincent de Paul
ROAD
Glebe Bay
Hillsmere Shores
"A"
Hill Point
Long
SCALE 1:24000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER

Figure 4.3

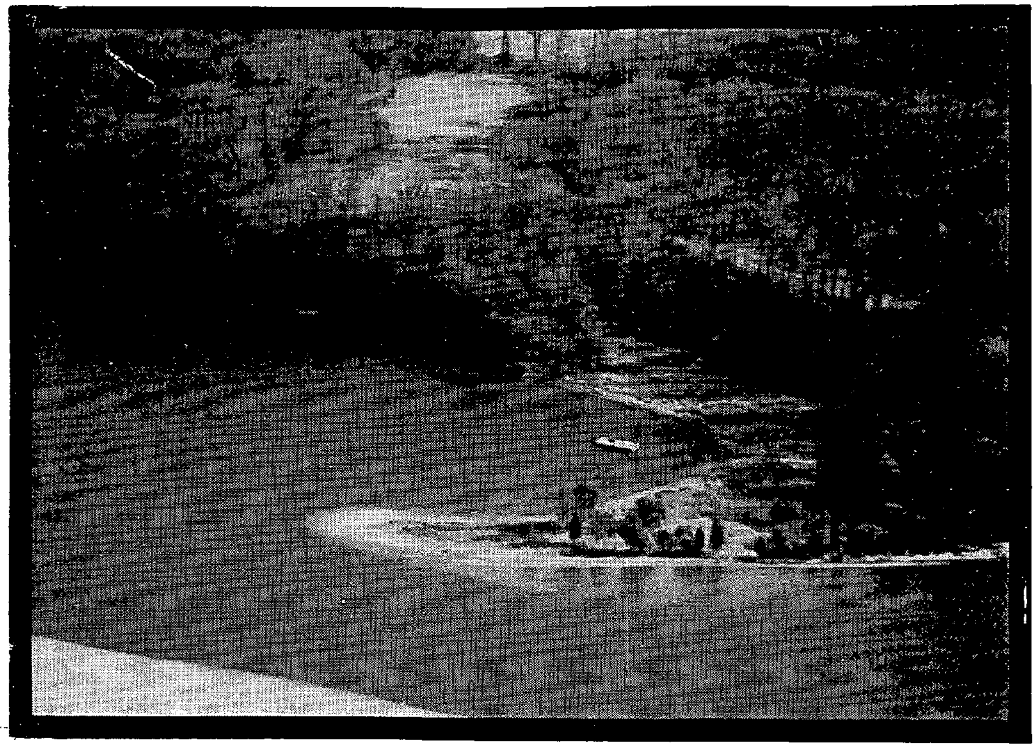

Figure 4.4

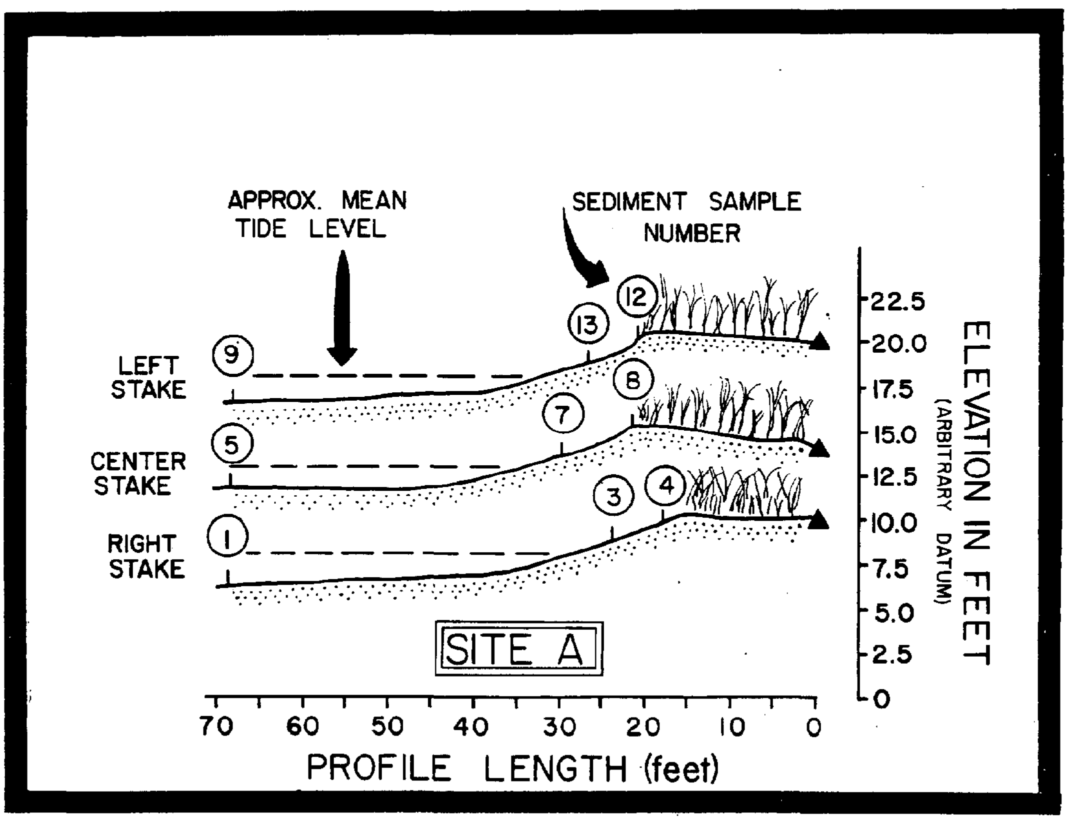

Figure 4.5

1.5 feet thick is also exposed in the scarp. The shells have been eroded and carried all along the beach to form a pavement over the lower foreshore and the immediate nearshore (Figure 4.6a). The eroding shell bed is composed solely of the shells of the oyster Crassostrea virginica, and it apparently represents a shell dump left by earlier inhabitants of the area.

The spit is densely vegetated with shrubs, grasses, and small cedar trees. Sand deposits on the shoreline profiles are very narrow with as little as six feet between the shoreface and the fringe of the vegetation. The profile locations are midway along the length of the spit, with the center profile situated 200 feet from the point of spit attachment.

The profile layout consists of three transects spaced 30 feet apart. Typical profiles (October 1978) are shown in Figure 4.5. In April 1979, the sediments were sampled from the beach in the upper 1-2 inches of the shoreline profiles and the textural characteristics of the sediments are shown in Table 4.2. The offshore zone is represented by samples taken 69 feet from the profile origins, and Table 4.2 shows sediments in this portion of the profile are sandy muds. In contrast, the beach materials represented by the foreshore samples Nos. 3, 7, and 11 are sand containing up to 20%

Next pages: Figure 4.6a-c Photographic view of the three profile locations at Site A in October 1978, May 1979, October 1979.

RIGHT

CENTER

LEFT

SITE "A" OCT. 1978

Figure 4.6a

RIGHT

CENTER

LEFT

SITE "A" MAY 1979

Figure 4.6 b

RIGHT CENTER LEFT

SITE "A" OCT. 1979

Figure 4.6c

TABLE 4.2

SEDIMENT CHARACTERISTICS; SITE A

Sample No.	Profile	Distance From Origin	Zone	*Gravel (>2.0 mm)		Sand (0.062mm to 2mm)		Silt (0.0039 to 0.062mm)		Clay (<0.0039 mm)	
				Mineral	Organic	Mineral	Organic	Mineral	Organic	Mineral	Organic
1	Right	69.0 ft.	Offshore	0.06 gm	-	42.49 gm	0.39 gm	35.91 gm	0.26 gm	17.20 gm	3.68 gm
3	Right	24.0	Foreshore	6.81	-	91.12	0.37	0.29	<0.01	0.30	1.11
4	Right	18.2	Fastland	2.90	-	93.75	0.57	0.57	<0.01	1.29	0.91
5	Center	69.0	Offshore	0.20	-	47.87	0.39	28.71	0.03	19.22	3.58
7	Center	30.0	Foreshore	20.46	-	76.34	0.46	0.33	<0.01	1.31	1.09
8	Center	22.3	Fastland	0.77	-	93.63	0.76	1.04	<0.01	2.74	1.05
9	Left	69.0	Offshore	0.96	-	36.85	0.26	38.05	0.04	20.04	3.80
11	Left	27.0	Foreshore	12.63	-	84.09	0.34	0.04	0.02	1.43	1.45
12	Left	21.7	Fastland	0.72	-	93.53	0.66	1.54	0.04	1.86	1.66

*The numerical values shown represent the fractional weight, in grams, of 100 grams of sample, thus the results may also be interpreted as percentage values.

gravel-size material. The boundary zone between the predominance of sand and mud in the nearshore occurs between 30 and 50 feet on the profiles. The fastland samples taken from the erosion scarp show a composition of sand with minor amounts of gravel; but, this scarp is not considered to be the principal source of the gravels in the beach sediments at the study site. The enrichment of gravels in the beach is probably due principally to the erosion of the downstream bluff, and movement of these materials along the shoreline onto the spit.

The shoreface of the spit receives boat-wake energy from boats entering and exiting Harness Creek, and from boats travelling up and down the South River. Since the width of Harness Creek is only about 500 feet in the vicinity of the profile stations, boats entering or leaving the creek pass relatively close to the shore where the study site is located. On the other hand, boats travelling on the South River commonly pass at distances greater than 1,000 feet from the study site. The boating characteristics at this site are discussed in Chapter VI.

The spit also receives wind waves which approach with the longest fetches from the east, south, and northwest. The wind-wave climate at this site is discussed in Appendix B, and the wind waves and boat wakes are compared in Chapter VII for their relative importance in causing any changes in the shoreline profiles.

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opposite: Table 4.2 Sediment characteristics at Site A. The locations of the samples listed in the table are shown on the profiles in Figure 4.5.

The fastland boundary at Site A was defined as the edge of vegetation. This boundary coincides with a pronounced break in slope formed by the upper foreshore of the beach. On some spring high tides during the year of observation, the wave uprush would reach the limit of vegetation to form a scarp. Photographic views of the three profiles which are shown in Figures 4.6 a,b,c for the months of October 1978, May 1979, and October 1979, respectively, were selected from all the monthly photographs to illustrate the conditions at the beginning and end of the "non-boating season" (October 1978 - May 1979), and at the end of the "boating season" (May 1979 October 1979). The complete monthly photographic coverage is on file at the Coastal Resources Division of the Maryland Department of Natural Resources.

Profile comparisons between successive months are shown in Figure 4.7. The envelope of total change is shown in Figures 4.8a and b. The combined profile overlay for the period October 1978 - May 1979 (Figure 4.8a) clearly shows the modulation of beach foreshore elevations from month to month, and the virtual absence of any change in the nearshore bottom. The greatest total vertical change within the envelope was at the upper foreshore adjacent to the fastland boundary.

The combined profile overlay for the period May-October 1979 (Figure 4.8b) shows that some modulation of foreshore elevation occurs during the boating season. There was also measurable retreat of about 0.5 feet in the fastland boundary on the left and right profiles during the boating season, but this is due principally to a fastland retreat solely in the profiles of 07/28/79 and 09/15/79. The changes in the shoreline profiles during this time period can be reasonably attributed to the influence of the passage of Tropical Storm David on September 5-6, 1979. During the passage of David, a storm surge of about 2.5 feet was generated in the vicinity of the study area along with strong winds from the southeast. Under these conditions, the entire spit was awash and subjected to wave and current energy.

It is important to note that during the boating season (the profile period 05/25/79 to 07/28/79), no retreat of the fastland occurred at any of the three profile stations. In fact, very little difference in foreshore elevation is evidenced in the profiles for those months. In order to emphasize the changes in the zone of the fastland boundary, segments of the monthly profiles which were collected through time are shown "stacked" in Figure 4.7. The vertical reference lines represent the position of the fastland boundary (edge of vegetation) in October, 1978. Again, note the absence of scarp retreat between the May and July surveys.

Next pages: Figure 4.7 (left) Profile comparisons between successive months at Site A.

Figure 4.8a (upper right) Profile overlay for Site A from October 1978 to May 1979.

Figure 4.8b (lower right) Profile overlay for Site A from May 1979 to October 1979.

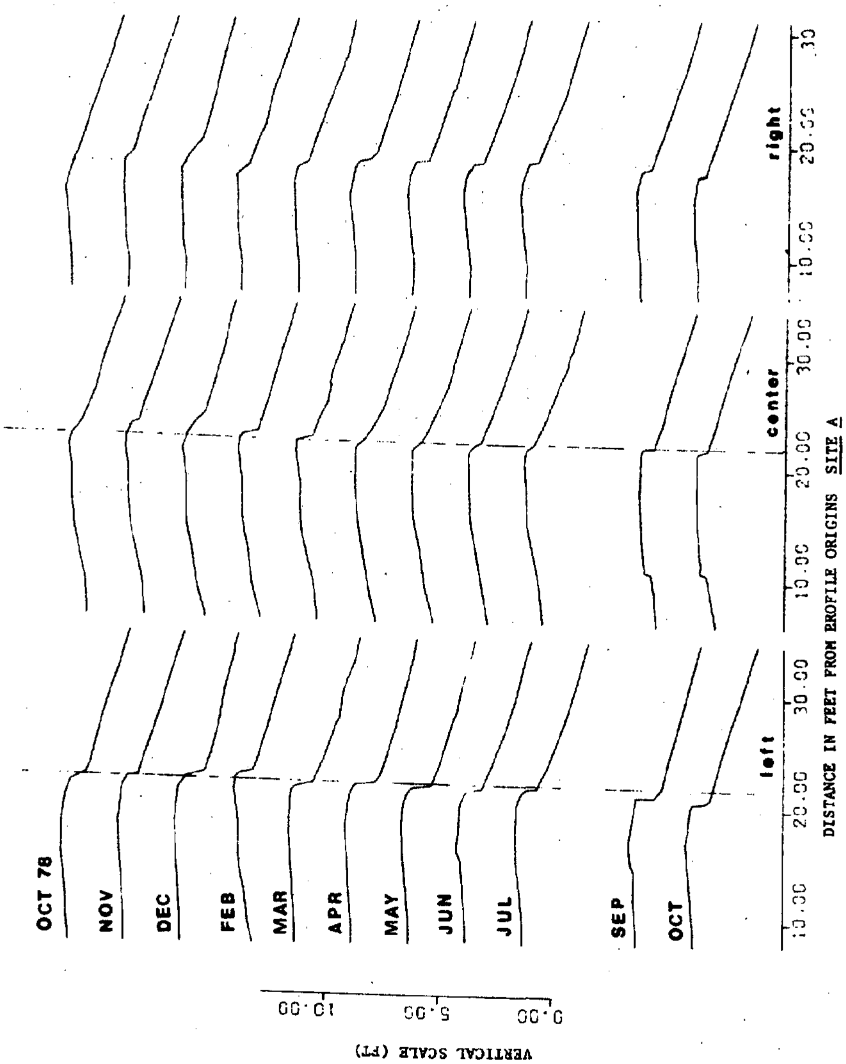
OCT 78
NOV
DEC
FEB
MAR
APR
MAY
JUN
JUL
SEP
OCT
left
center
right
10.00
20.00
30.00
DISTANCE IN FEET FROM PROFILE ORIGINS SITE A
0.00
5.00
10.00
VERTICAL SCALE (FT)

Figure 4.7

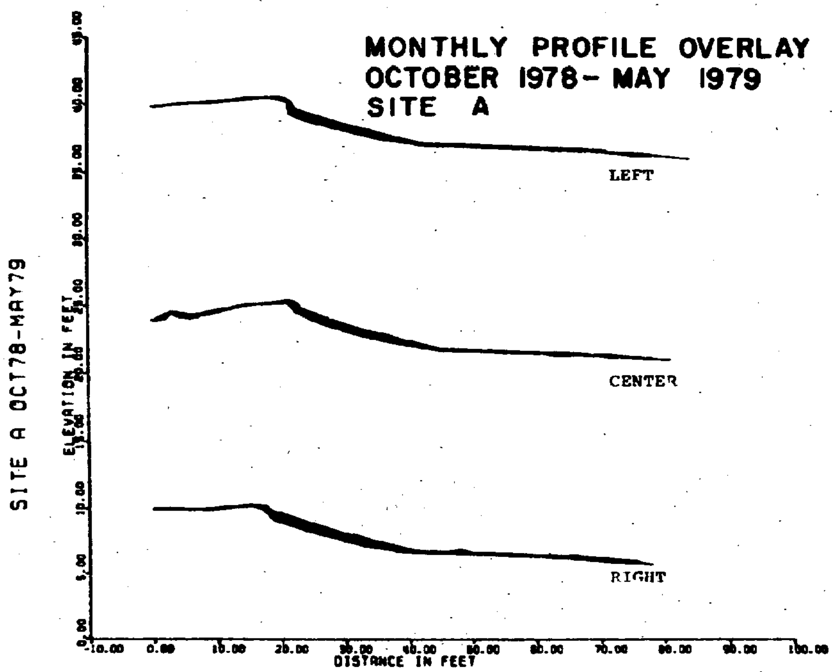

Figure 4.8 a

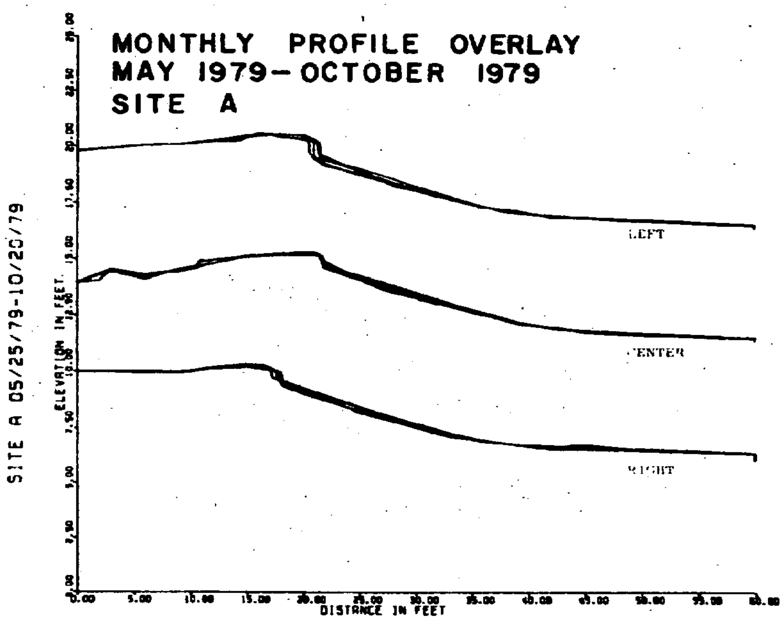

Figure 4.8 b

The evidence from the monthly surveys and photographs indicates there was very little change in the position of the fastland boundary during the year of observations. The scarp between the edge of the active vegetation and the beach foreshore varied in elevation and steepness through the course of the year along with a variation in the volume of foreshore sand at the shoreline site. This modulation in beach sand occurred in response to varying wave conditions and water levels. The profiles collected during the "boating season" on 05/25/79, 06/23/79, and 07/28/29 are virtually identical. Thus, boat wake activity did not cause measurable monthly changes at Site A during that period. The fastland retreat which was observed in the survey of 09/15/79 at two of the profiles is attributed to the wave and water level conditions during Tropical Storm David.

Site B. A steep bank on the upper South River near Goose Island.

This site is located near the subdivision known as Glen Isle (Figures 4.9, 4.10, 4.11). The beach segment chosen for monitoring is located in a bluff section on the south shore of the upper South River, about 700 feet downstream from the mouth of Flat Creek. The sediments on the beach at the study site are derived principally from the bluff, but the finer-grained sediments in the nearshore may be derived principally from the sediment discharge of Flat Creek. The bluff has a maximum height of about 30 feet, and a frontal slope of about 45 degrees. It is composed of semi-consolidated clayey sands of the Aquia Formation (Eocene Age) that contain impermeable lenses of sediment cemented into a sandstone-type material. As the bluff has eroded, these limonitic deposits have fallen onto the beach at the base on the bluff and form a rubble pavement on the shoreline profile.

The bluff extends for about 500 feet along the upper South River shoreline, from the mouth of Flat Creek to a marsh which has formed at the mouth of a ravine. There

Next pages: Figure 4.9 (left) Location map showing Site B.

Figure 4.10 (upper right) Aerial view of Site B.

Figure 4.11 (lower right) Typical profile of Site B in November 1978.

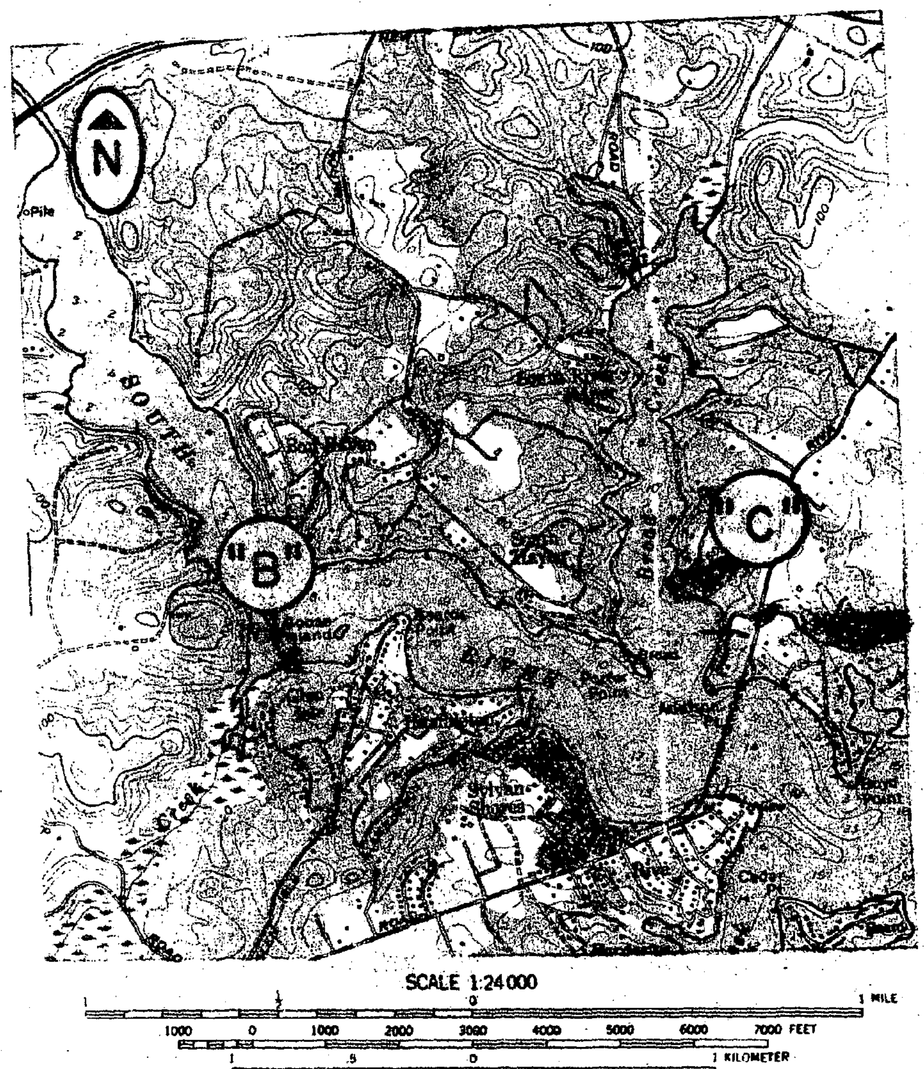
N
"B"
"C"
SOUTH
SCALE 1:24000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

Figure 4.9

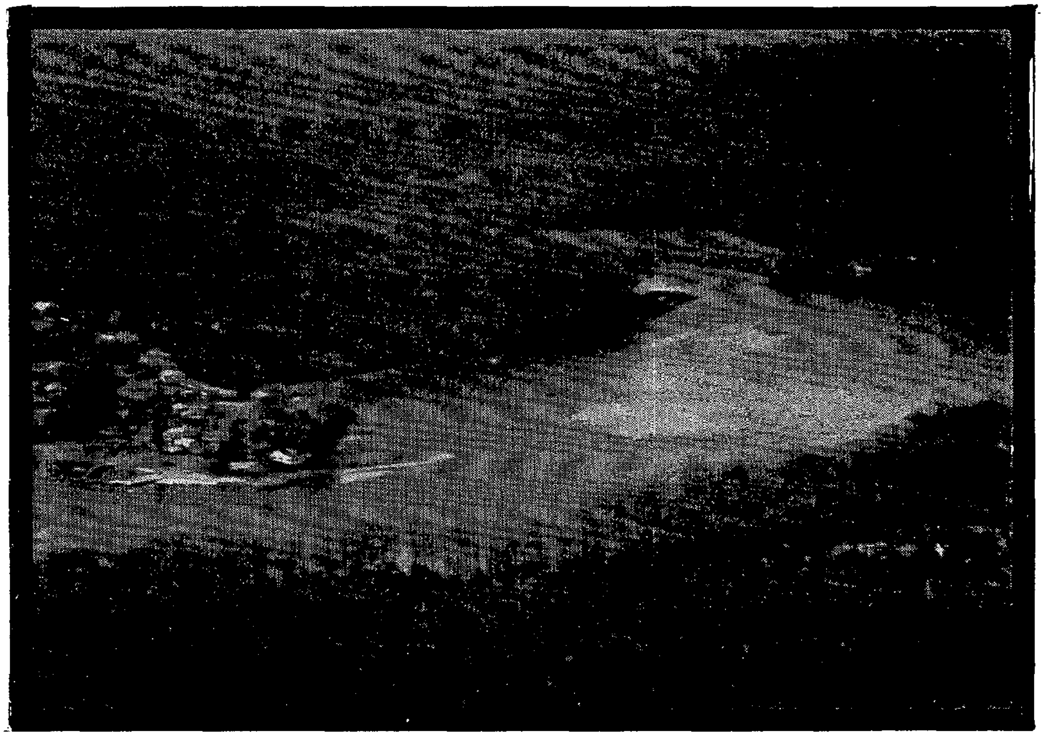

Figure 4.10

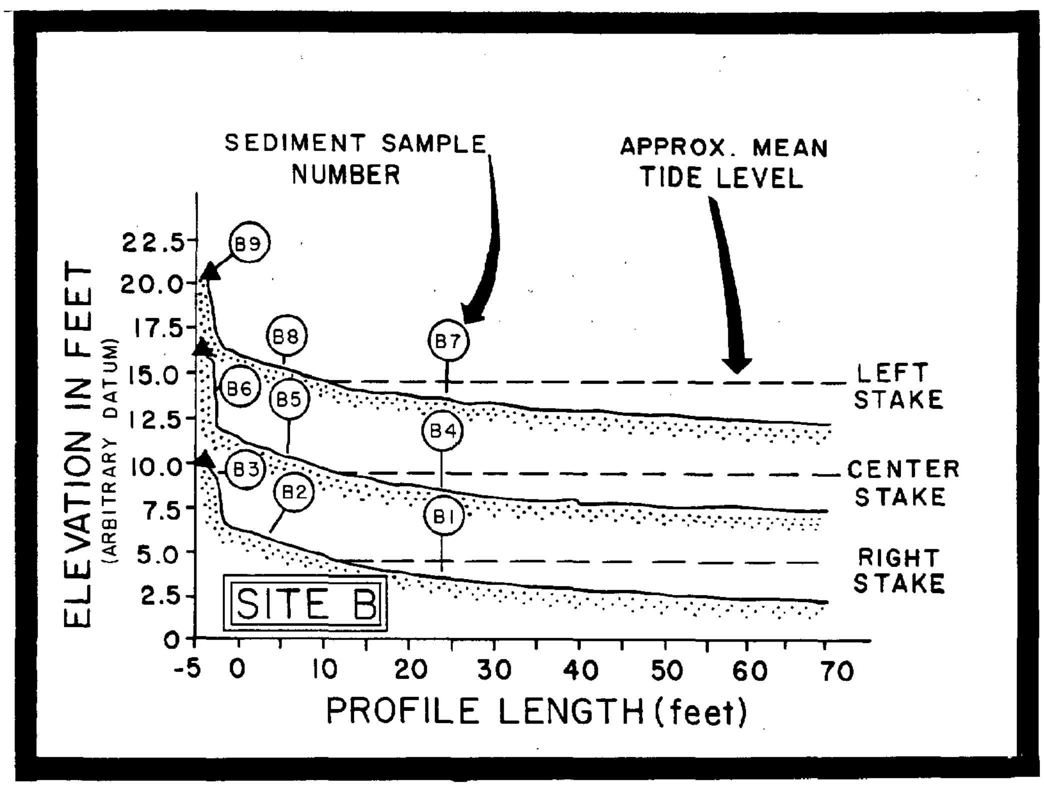

Figure 4.11

TABLE 4.3

SEDIMENT CHARACTERISTICS; SITE B

Sample No.	Profile	Distance From Origin	Zone	*Gravel (>2.0 mm)		Sand (0.062mm to 2mm)		Silt (0.0039 to 0.062mm)		Clay (<0.0039 mm)	
				Mineral	Organic	Mineral	Organic	Mineral	Organic	Mineral	Organic
B1	Right	24.0 ft.	Nearshore	18.71 gm	-	66.11 gm	1.60 gm	4.23 gm	1.04 gm	6.15 gm	2.15 gm
B2	Right	3.0	Foreshore	5.04	-	83.81	0.76	1.34	0.05	7.13	1.87
B3	Right	-3.1	Bluff	1.48	-	68.44	3.00	14.26	0.75	11.54	3.52
B4	Center	24.0	Nearshore	22.17	-	65.08	0.86	4.43	0.30	4.84	2.32
B5	Center	5.0	Foreshore	11.92	-	82.26	0.41	0.82	<0.01	2.72	1.86
B6	Center	-2.4	Bluff	1.51	-	77.40	0.86	3.89	0.09	13.67	2.58
B7	Left	24.0	Nearshore	44.28	-	43.70	0.53	4.60	0.03	5.06	1.80
B8	Left	5.0	Foreshore	2.84	-	85.91	0.87	1.62	0.30	6.72	1.74
B9	Left	-4.2	Bluff	6.48	-	78.71	0.80	0.42	<0.01	11.83	2.26

*The numerical values shown represent the component weight, in grams, of 100 grams of sample, thus the results may also be interpreted as percentage values.

are mature trees and shrubs located on the top of the bluff, and the upper portions of the bluff face are covered with a slumped and hanging mass of soil and roots.

The mean tide range at the site is about 1.0 foot, and there were no shoreline structures present along the reach during the period of study.

Sand deposits on shoreline profiles at this site are narrow, with as little as 10 feet between the shoreface and the toe of the bluff. The profile locations for the study are located at the downstream end of the bluff, where the land surface slopes into the ravine, and just before the beach joins with the marsh. The profile layout consists of three transects spaced 30 feet apart. Typical profiles (November 1978) are shown in Figure 4.11. In April 1979, the sediments were sampled from the beach in the upper 1-2 inches of the shoreline profiles, and the textural characteristics of the sediments are shown in Table 4.3. The offshore zone is composed of soft, fine-grained muds which blend into a relatively firm sandy bottom about 30 feet from the shoreline. These sands on the beach and in the nearshore possess a significant gravel content which represents the lag deposit left on the shoreline profile as the bluff recedes. Sediment samples from the bluff are composed predominantly of sand, but with a significant

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Opposite: Table 4.3 Sediment characteristics at Site B. The locations of the samples listed in the Table are shown on the profiles in Figure 4.11.

fine-grained component. As the bluff sediments erode, the finer-grained sediments are winnowed from the talus deposits at the base of the bluff by wave action and transported into deeper water.

The shoreface of the bluff receives boat-wake energy mostly from boats travelling the South River at distances of more than 1,000 feet. Some localized boat activity is generated from a smaller number of boats which circle Goose Island and pass within 100-200 feet of the study site. The boating characteristics at the site are discussed in Chapter VI.

The bluff site also receives wind waves which approach with the longest fetches from the north-northwest. Regional winds from this direction can generate appreciable wave energy which would focus on the site; but, these winds also tend to drive water out of the rivers on the western shore so that the erosive power of the waves tends to be expended at low levels on the beach and in the nearshore, rather than on the toe of the bluff. The wind-wave climate at this site is discussed in Appendix B, and the wind waves and boat wakes are compared in Chapter VII for their relative importance in causing any changes in the shoreline profiles.

The fastland boundary at Site B was defined as either the in-place semi-consolidated sediments forming the bluff, or the material which slumped from the bluff face. The reason for considering the slumped material as "fastland" is that were it not for the removal of this material by wave action, the bluff slope would ultimately be reduced and become stabilized with vegetation.

The initial condition of the profile sites is shown in the photographs of October, 1978 (Figure 4.12a). The Right profile is at a position where the bluff elevation is low and the semi-consolidated sediments were covered with a soil horizon. At the Center profile, the fastland is slumped material with limonitic fragments at the base, along with a notch about 0.75 feet deep cut into the sediment. The Left profile is a near-vertical cut of the native bluff sediments with a toe of limonitic fragments.

Figures 4.12b, b, and d show the condition at the profiles in May, August, and October, 1979 respectively. Profile comparisons between successive months are shown in Figure 4.13. The envelope of total change is shown in Figures 4.14a and b for the periods October 1978 - May 1979 respectively. The combined profile overlay shows there was no change in the fastland throughout the entire year at the Right profile, simply a modulation of the sand elevation in the beach at the toe of the bluff. During the period October 1978 - May 1979, the Left and Center profiles show an episode of slumping and reduction of the slump by wave action. During the period May-October, 1979, there was some further modification of the slumped material at the Center

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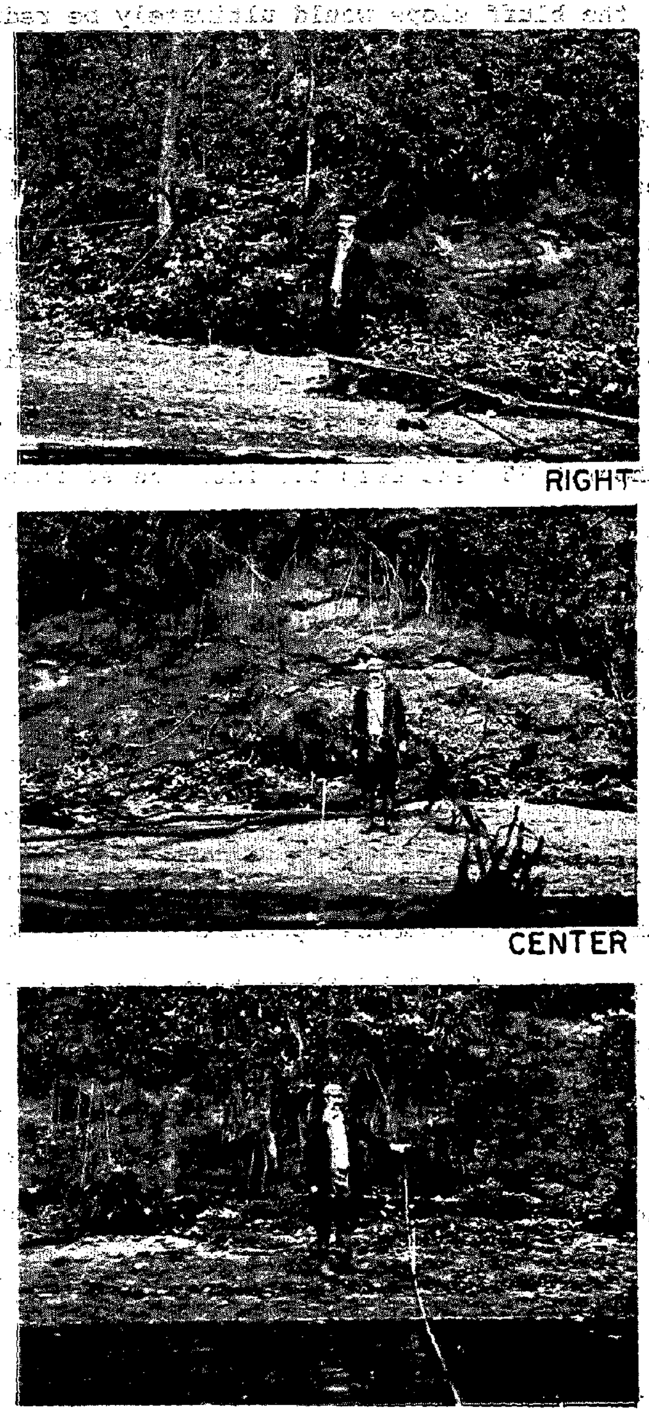
Next pages: Figure 4.12 a-d. Photographic views of the three profile locations at Site B in October 1978, May 1979, August 1979, October 1979.



RIGHT

CENTER

LEFT

SITE "B" OCT. 1978

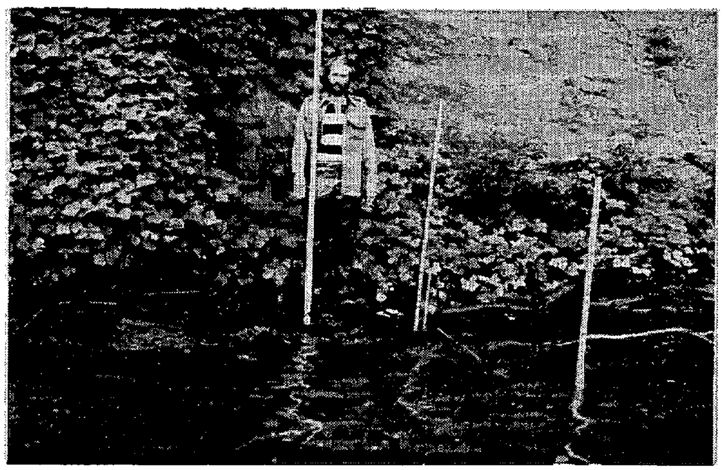
Figure 4.12a

RIGHT CENTER LEFT

SITE "B" MAY 1979

Figure 4.12b

RIGHT



CENTER

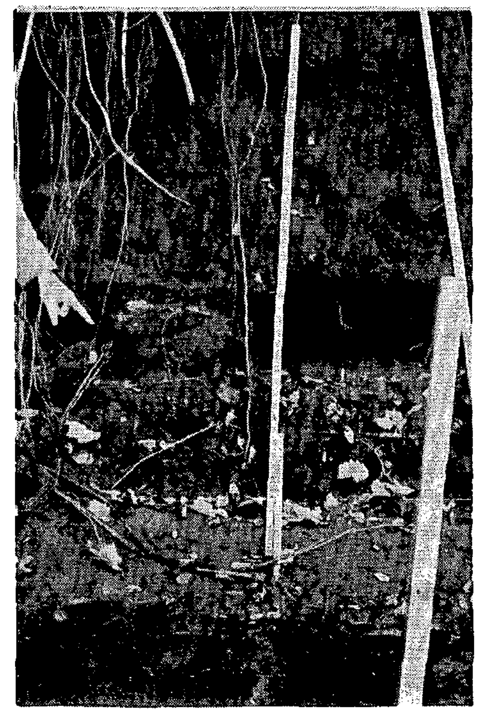
LEFT

SITE "B" AUG. 1979

Figure 4.12c

RIGHT

CENTER



LEFT

SITE "B" OCT. 1979

Figure 4.12d

and Left profiles, and again no change in fastland at the Right profile.

A different view of the fastland boundary changes is provided in Figure 4.13. This figure shows that no change in the Right profile occurred throughout the entire year, while the Center profile showed no change in fastland until sometime between the February and March 1979 surveys, when a massive slump occurred. The slumped material underwent some reduction by wave action until April-May 1979, and then only very minor modification until the passage of Tropical Storm David in September 1979. The Left profile shows minor slumping between October-December 1978, and a massive slump between December 1978 and early February 1979. The slumped material was again reduced by wave action in February, March, and April. However between the late May and late August surveys in 1979, there was little modification. Tropical Storm David in September was accompanied by a substantial reduction of the slumped material, and Figure 4.12d shows the native bluff material was again exposed after David.

All the evidence indicates there was little modification of the fastland at this site during the boating season. However, there was significant modification of two of the three profile locations with the passage of Tropical Storm David. Figure 4.13 shows the approximate level of the storm tidal surge during the David episode. This site was apparently not exposed to much high wave action since the wind was predominantly from the southeast and south. Even so, the shoreline profiles collected after David show the slumped material at the Center and Left profiles was reduced. The Right profile showed no change.

In summary, it should be noted that very minor changes occurred during the boating season of 1979. Comparison of the month-to-month surveys shows this was the period of least response in the shoreline profiles to wave activity during the year of observations.

Next pages: Figure 4.13 (left) Profile comparisons between successive months at Site B.

Figure 4.14a (upper right) Profile overlay for Site B from October 1978 to May 1979.

Figure 4.14b (lower right) Profile overlay for Site B from May 1979 to October 1979.

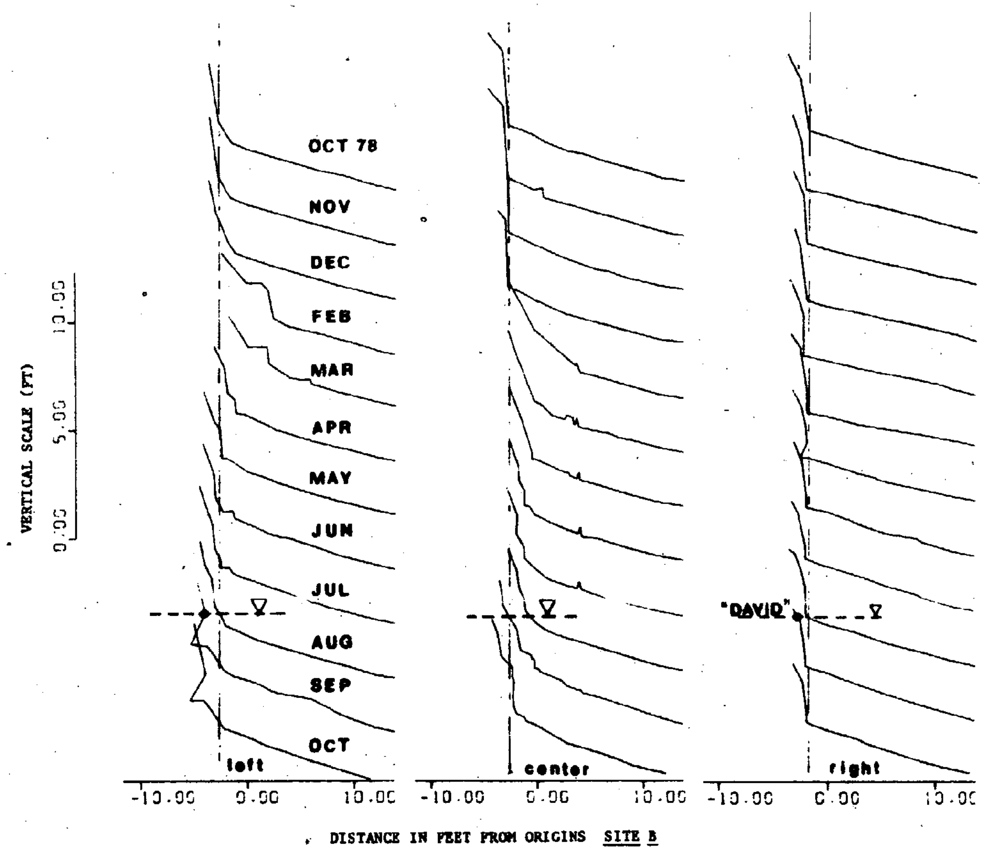

VERTICAL SCALE (FT)
0.00
5.00
10.00
OCT 78
NOV
DEC
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
"DAVID"
left
center
right
-10.00
0.00
10.00
DISTANCE IN FEET FROM ORIGINS SITE B

Figure 4.13

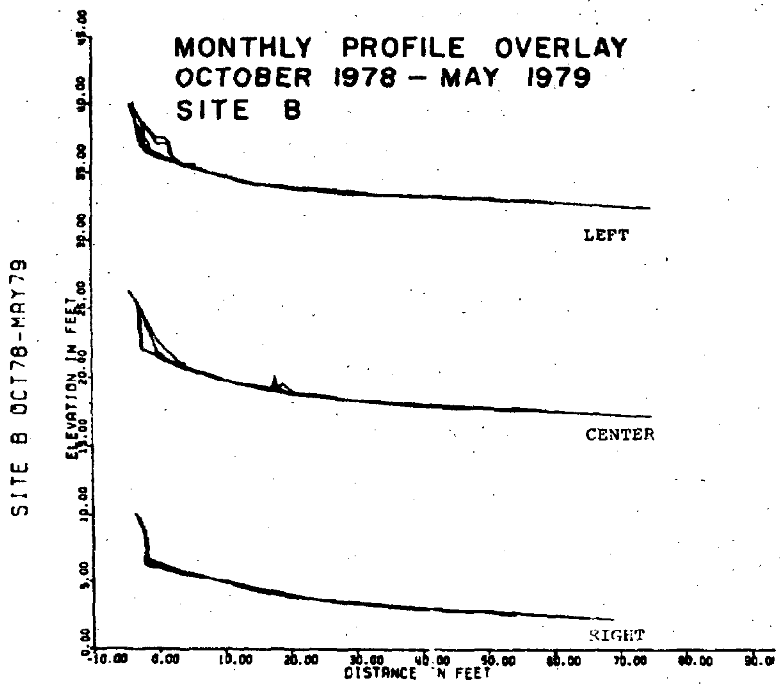


Figure 4.14 a

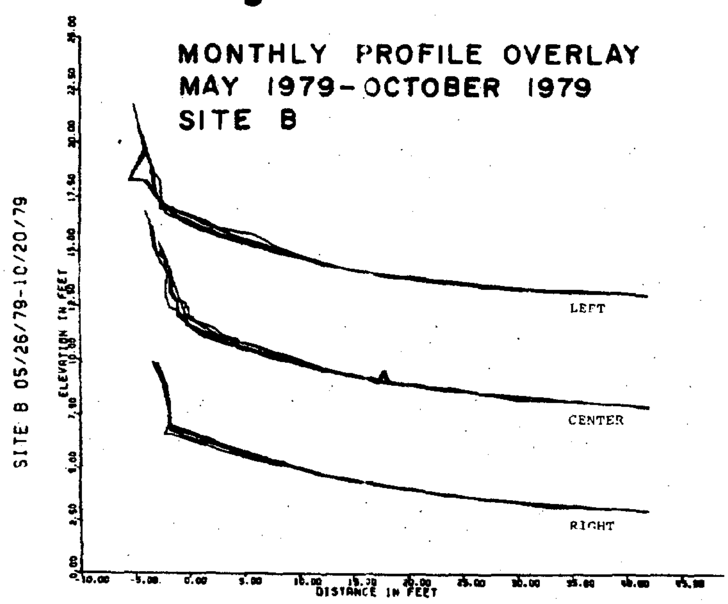


Figure 4.14 b

Site C. A broad, marshy promontory on Broad Creek off the upper South River.

This site is located approximately 1200 feet north of the mouth of Broad Creek (Figure 4.15, 4.16, 4.17). The shoreline segment chosen for monitoring is located on a promontory at the junction of a north-south shoreline reach and another trending east-west. The promontory is composed of a low, marsh-capped, alluvial platform which is surrounded by hills attaining elevations of up to 60 feet within 500 feet of the study site. This adjacent topography is sculptured from sandy deposits of the Aquia Formation (Eocene Age).

The sediments at the study site were derived partially from the erosion of these adjacent landforms. Various exhumed debris from along the shoreline near the study site indicates that the site may also be partially composed of artificial fill. Upstream of the promontory for a distance of about 100 feet along the shoreline are the remains of a concrete wall which are columnar in section, and about one-foot-square. These remains no longer provide an effective barrier to shoreline erosion as they lay on the bottom of Broad Creek several feet from the fastland at the study site.

In the area where the profiles were located, the promontory forms a portion of the Broad Creek shoreline about 130 feet in length. The fastland at the study site is relatively flat, with an overwash "levee" present on the marsh surface (Figure 4.17). The marsh itself is flooded at higher tidal stages, and is composed of _Spartina patens_, _Scirpus_, and _Distichlis_ grass species.

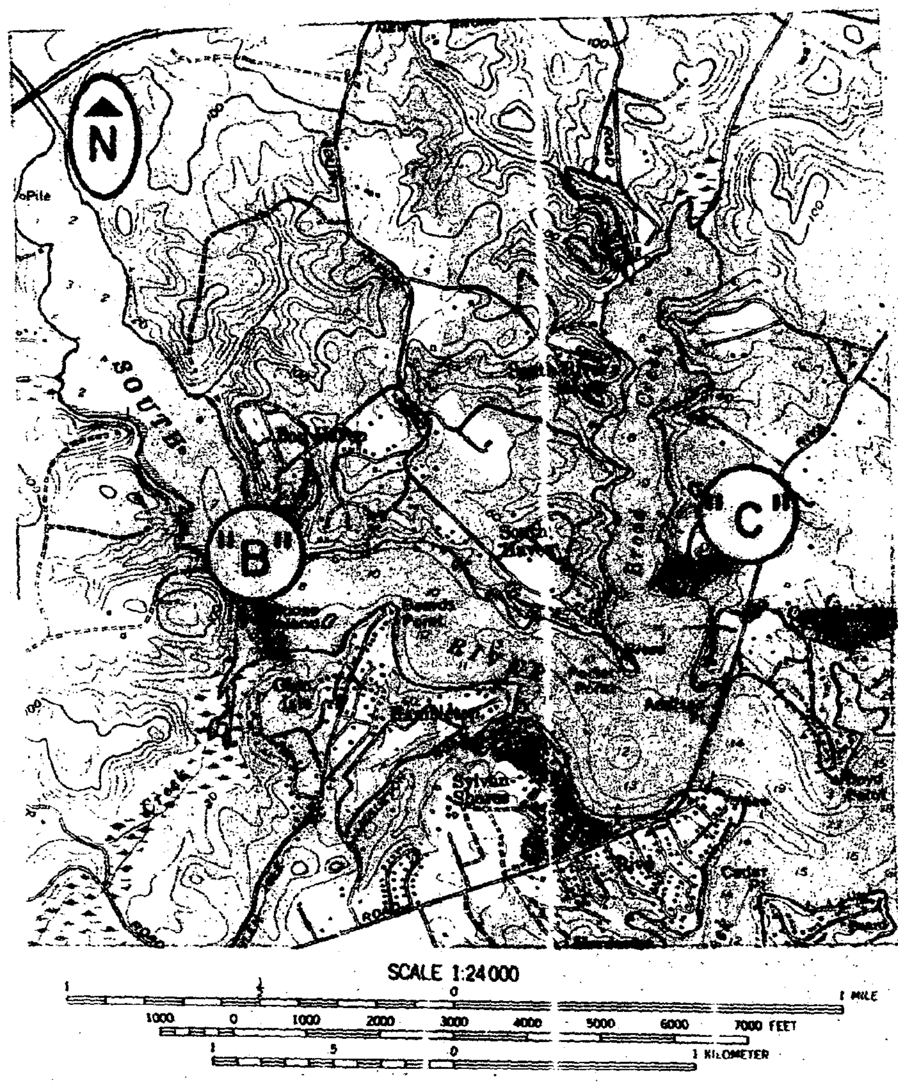
The mean tide range in the area is about 1.0 foot, and there were no shoreline structures present along the reach during the period of study.

Sand deposits on the shoreline profiles are narrow with as little as 10 feet between the shoreface and edge of the marsh. The profile locations are situated on the promontory along the east side of Broad Creek facing the west. The profile layout consists of three transects spaced 30 feet apart. Typical profiles (October, 1978) are shown in Figure 4.17. In April 1979, sediments were sampled from the beach in the upper 1-2 inches of the shoreline profiles, and the textural characteristics of the sediments are shown in Table 4.4. The sediments in the foreshore, nearshore, and offshore (up to 69 feet from the profile origins) are all predominantly sand size with small contributions of organics. The composition of the terrace sediments is shown in a boring sample M1. The upper 2-3 inches of the boring are an organic soil with an abrupt transition below to a sandy gravel.

Next pages: _Figure 4.15_ (left) Location map showing Site C.

Figure 4.16 (upper right) Aerial view of Site C.

Figure 4.17 (lower right) Typical profile of Site C in October 1978.



N
"B"
"C"
SOUTH
SCALE 1:24 000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER

Figure 4.15

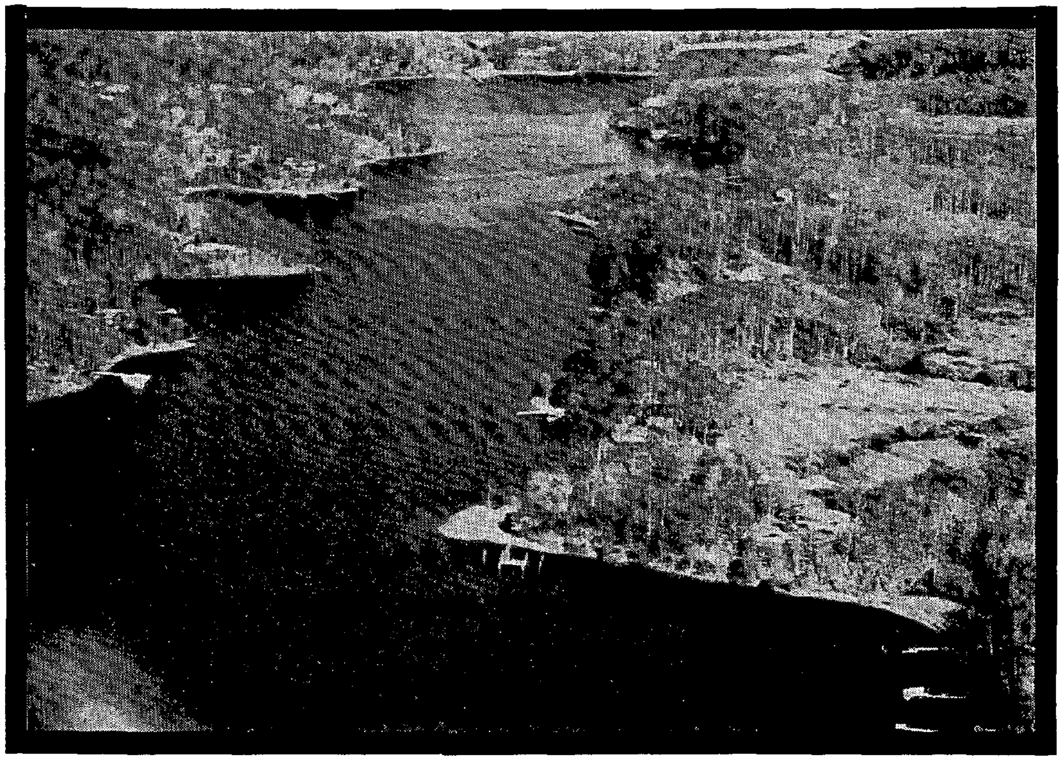


Figure 4.16

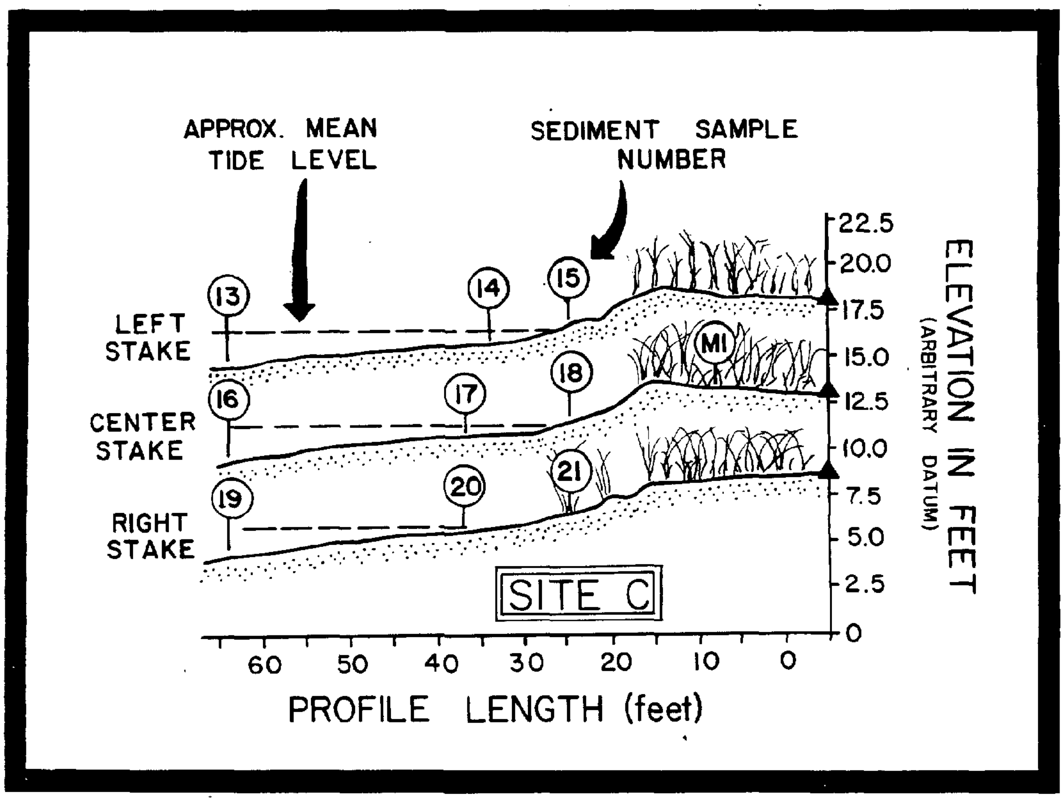


Figure 4.17

TABLE 4.4

SEDIMENT CHARACTERISTICS; SITE C

Sample No.	Profile	Distance From Origin	Zone	*Gravel (<2.0 mm)		Sand (0.062mm to 2mm)		Silt (0.0039 to 0.062mm)		Clay (<0.0039 mm)	
				Mineral	Organic	Mineral	Organic	Mineral	Organic	Mineral	Organic
19	Right	69.0 ft.	Offshore	3.58	-	89.79	0.54	1.25	0.12	3.01	1.70
20	Right	42.0	Nearshore	2.20	-	90.90	0.36	1.57	0.08	2.98	1.91
21	Right	30.0	Foreshore	7.49	-	87.92	0.26	0.75	0.13	1.51	1.94
16	Center	69.0	Offshore	2.10	-	91.26	0.55	1.85	0.19	2.48	1.57
17	Center	42.0	Nearshore	0.84	-	93.66	0.28	1.00	0.38	2.14	1.71
18	Center	30.0	Foreshore	15.60	-	80.90	0.24	0.67	<0.01	1.00	1.59
M1	Center	13.0	Marsh Terrace	47.49	-	46.94	0.19	2.14	0.40	0.88	1.98
13	Left	69.0	Offshore	1.02	-	93.84	0.38	0.96	0.10	1.74	1.96
14	Left	39.0	Nearshore	1.59	-	89.90	0.45	1.94	1.04	3.13	1.94
15	Left	30.0	Foreshore	0.78	-	94.82	0.48	0.57	0.33	1.40	1.63

*The numerical values shown represent the fractional weight, in grams, of 100 grams of sample, thus the results may also be interpreted as percentage values.

The shoreface of the promontory receives boat-wake energy from boats travelling up and down Broad Creek. The site is downstream from a posted speed-control zone, and both high- and low-speed boat passes are encountered. Due to the relatively narrow width of the creek in the area, the study site is positioned particularly close to boats generating wake. The boating characteristics at this site are discussed in Chapter VI.

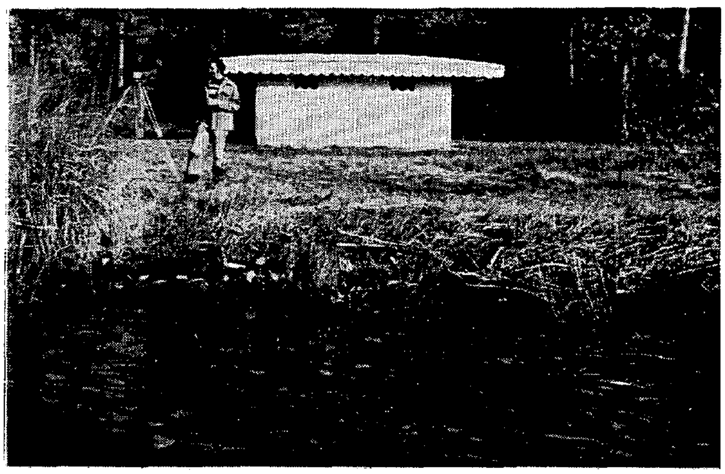
The site also receives wind waves which approach with the longest fetches from the north. But waves generated by these northern winds have to undergo considerable refraction to approach the study site from directly offshore, so the wind-wave energy at this site is considered to be small relative to sites with similar fetches on the South River. The wind-wave climate at this site is discussed in Appendix B and the wind waves and boat wakes are compared in Chapter VII for their relative importance in causing any changes in the shoreline profiles.

The initial condition of the profile sites is shown in the photographs of October, 1978 (Figure 4.18a). The fast-land boundary was defined as the edge of the marsh vegetation capping the sand and gravel terrace. At all three profile locations, collapsed patches of the cap marsh were growing on the intertidal foreshore of the narrow beach.

Opposite: Table 4.4 Sediment characteristics at Site C. The locations of the samples listed in the Table are shown on the profiles in Figure 4.17.

Next pages: Figure 4.18 a-d Photographic view of the three profile locations at Site C in October 1978, May 1979, August 1979, and October 1979.

RIGHT

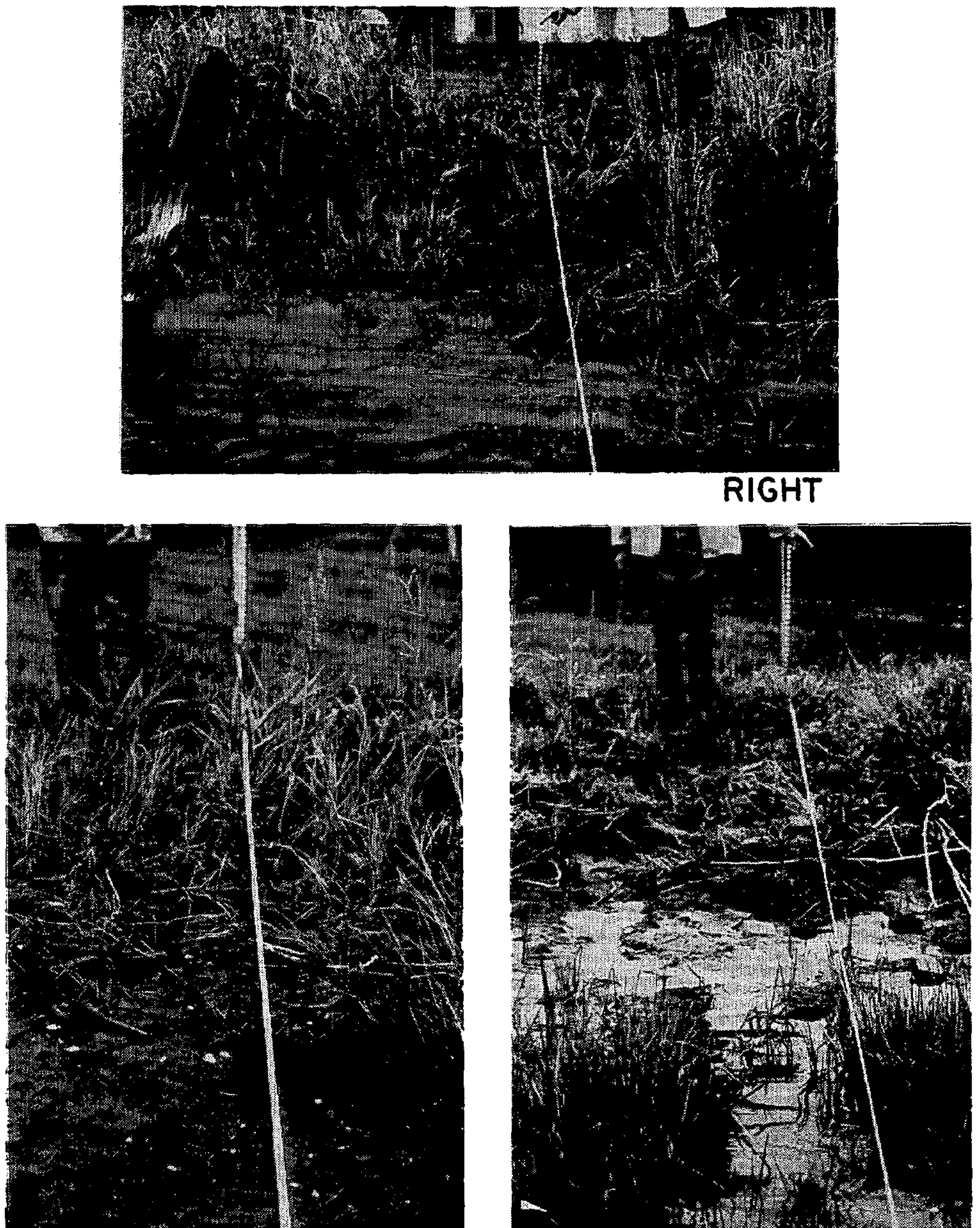


CENTER

LEFT

SITE "C" OCT. 1978

Figure 4.18a



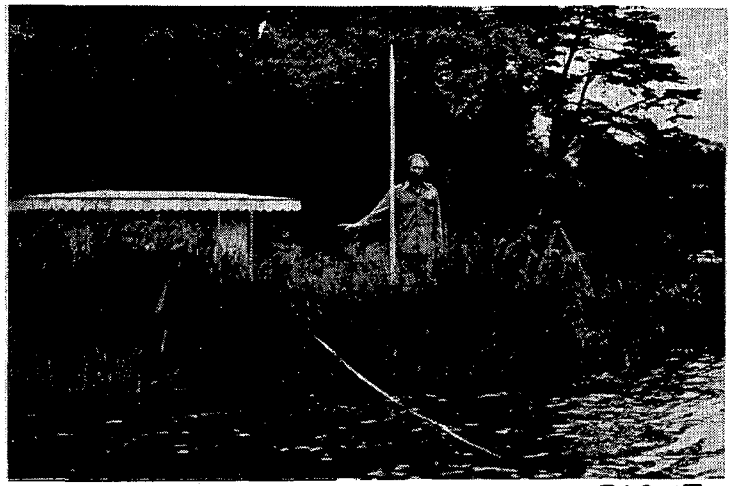
RIGHT

CENTER

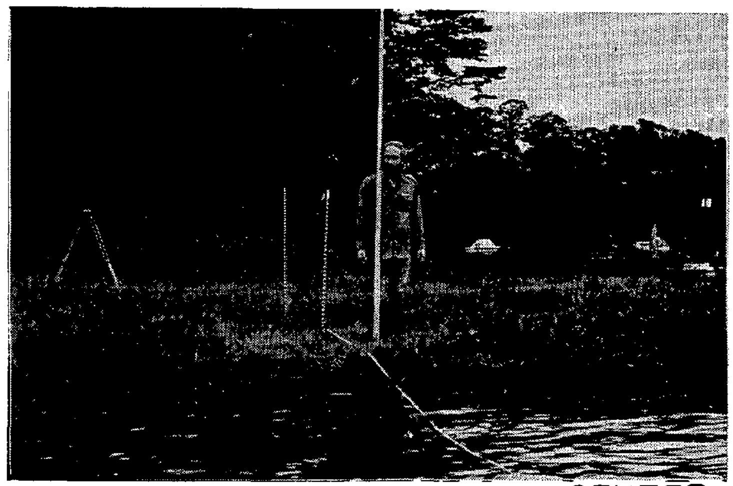
LEFT

SITE "C" MAY 1979

Figure 4.18 b



RIGHT

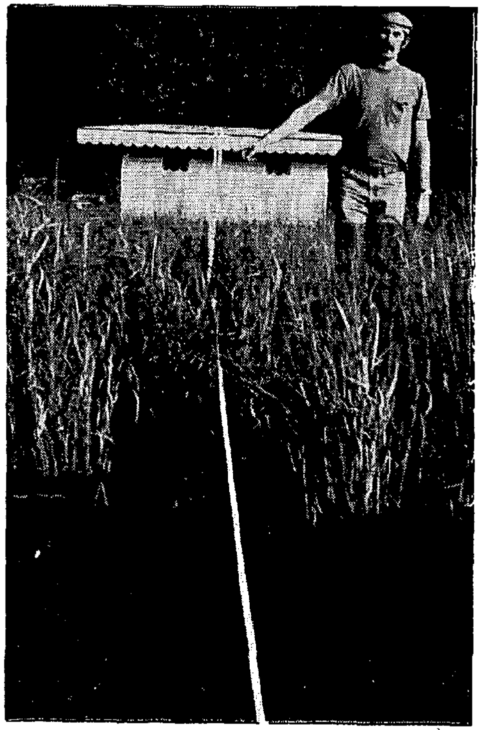


CENTER

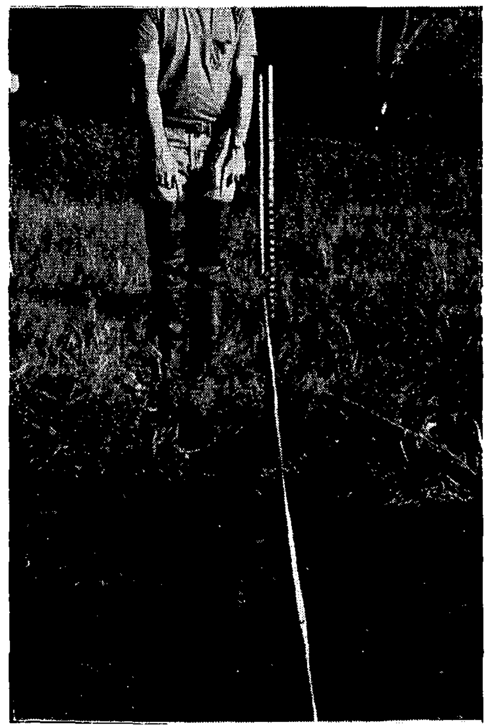
LEFT

SITE "C" AUG. 1979

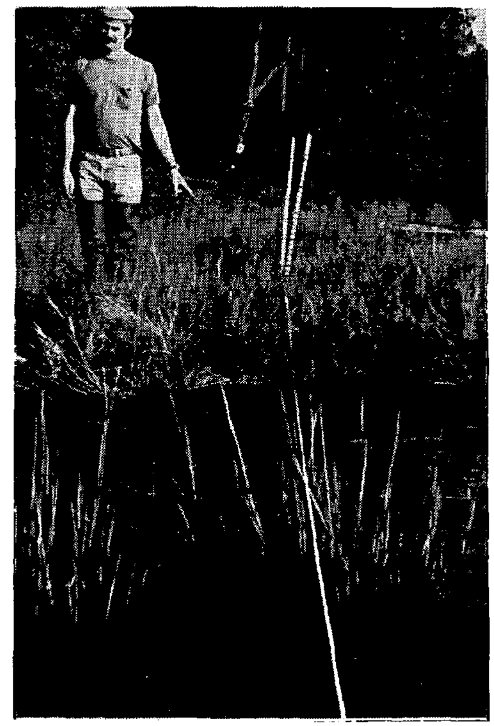
Figure 4.18c



RIGHT



CENTER



LEFT

SITE "C" OCT. 1979

Figure 4.18d

The overlays of monthly profiles for the periods October 1978-May 1979 and May - October 1979 are shown in Figures 4.20a and b. Both the Left and Center profiles reflect the existence of the slight positive relief on the terrace due to an overwash deposit formed by wave action awashing foreshore sand onto the marsh surface during times of high water. In addition, the different geometry of the profiles near the fastland should be noted. Comparison of Figs. 4.20a and b shows a rather dramatic difference in the fastland response between the boating and non-boating seasons. During the boating season a pronounced retreating scarp formed at the Left profile. At the Center profile the preexisting scarp continued to retreat. The Right profile exhibited no fastland retreat throughout the year. The details of the observed fastland boundary retreat are shown in Figure 4.19. The Left profile, within 15 feet of the downstream end of the marsh terrace, had a slight scarp at the edge of vegetation which was stable in position until after the February 1979 survey. Between February and May 1979, the edge of vegetation retreated 3.7 feet but with only slight scarp formation. By the time of the June survey, a pronounced scarp had formed. By the time of the survey of 18 August 1979, the fastland scarp retreated an additional 2.6 feet. Finally, between 18 August and 20 October 1979, an additional 0.5 feet of retreat occurred. This loss includes the effects of Tropical Storm David. In total, about 6.8 feet of fastland retreat occurred during the one year period.

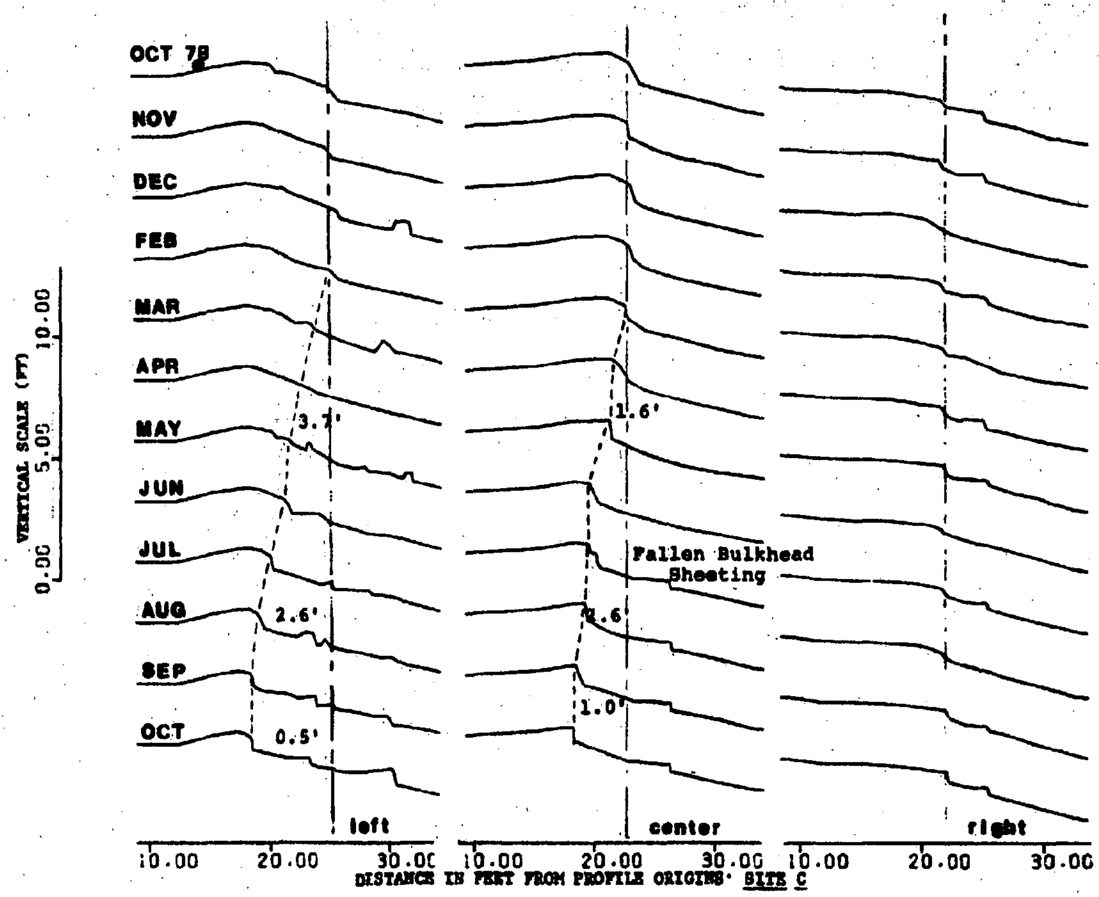
The Center profile had a pronounced scarp at the fastland boundary throughout the period. The scarp position was stable until after the March 1979 survey, and between that time and the survey of 26 May 1979 the scarp retreated 1.6 feet. Between the May survey and that of 18 August, the scarp retreated an additional 2.6 feet, most of which occurred between the May and June surveys. Between the June and July surveys, fallen bulkhead sheeting was exposed in the foreshore. Finally, between August and October 20, 1979, an additional 1.0 foot of retreat was measured. The total fastland retreat was 5.2 feet during the course of the year.

In summary, the pattern of fastland erosion at Site C appears to be that of a smoothing process which is tending to round the exposed corner of the marsh terrace (see Fig. 4.16). An important factor in this process may be the physical setting of the site. It is important to note that there is very little sand supplied to the site from the more erosion-resistant upstream banks. Were there sand available from this upstream source it would tend to maintain a beach in front of the marsh. Instead, the local intertidal beach is composed of materials eroded from the terrace, which is itself composed of a highly erodible, loose sand and gravel.

Next pages: Figure 4.19 (left) Profile comparisons between successive months at Site C.

Figure 4.20a (upper right) Profile overlay for Site C from October 1978 to May 1979.

Figure 4.20b (lower right) Profile overlay for Site C from May 1979 to October 1979.



VERTICAL SCALE (FT)
0.00
5.00
10.00
OCT 78
NOV
DEC
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
3.7'
2.6'
0.5'
1.6'
.6'
1.0'
Fallen Bulkhead Sheeting
left
center
right
10.00
20.00
30.00
DISTANCE IN FEET FROM PROFILE ORIGINS· SITE C

Figure 4.19

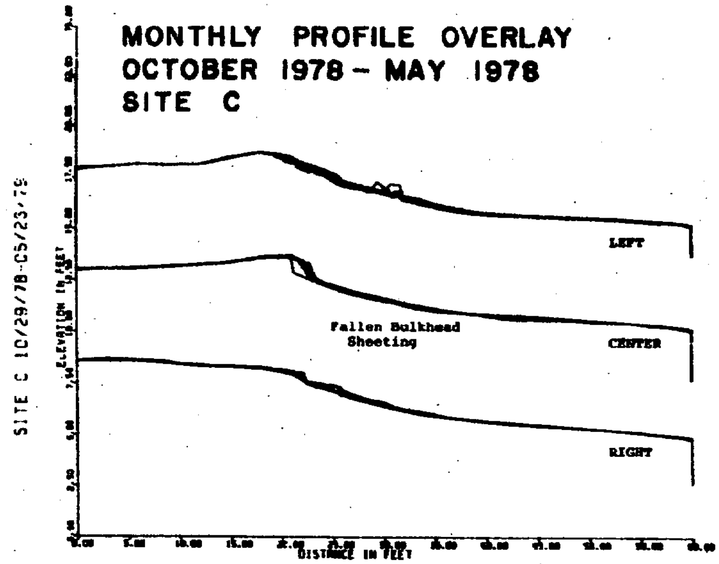


Figure 4.20a

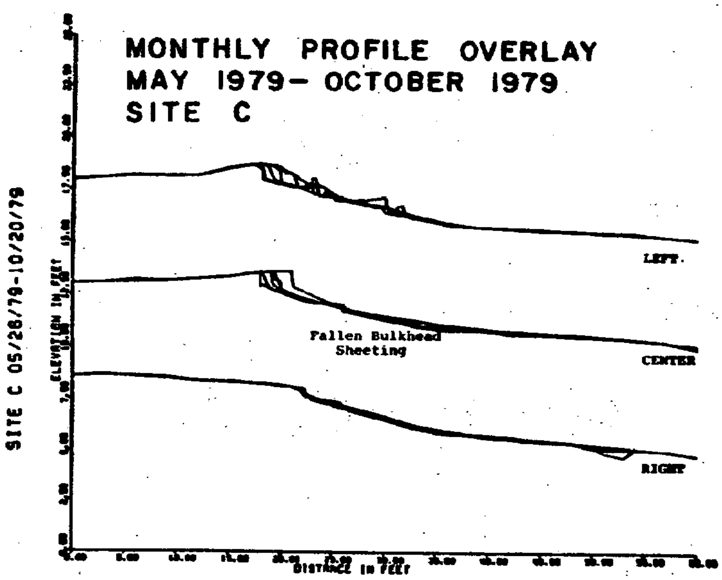


Figure 4.20b

Since materials including bricks and old bulkhead sheeting were exhumed from this site during the course of the year of study, it appears that at least part of the site is constructed of fill material.

Site D. A bluff on the lower Severn River at Severnside.

This site is located on the north shore of the Severn River approximately 4,000 feet southeast of the Route 50-301 Severn River Bridge (Figures 4.21, 4.22 and 4.23), at the region called Severnside. The shoreline reach in which the site is situated is about 4,500 feet in length extending from Brice Point in the southeast to a terminal spit in the northwest. With the exception of the vicinity of Brice Point and a ravine drainage, the entire reach is composed of bluffs as high as 80 feet in elevation. The bluffs are composed of semiconsolidated clayey sand (Aquia Formation) which in places stands at the near vertical.

Trees and shrubs are present on the top of the bluff, and vines and shrubs cover some potions of the bluff face. Some fallen trees and driftwood litter the shoreline near the study site, and the only shore protection structure in the immediate vicinity is a short 20-foot, cement-block-rubble groin about 230 feet southeast of the profiles. This short groin has no influence on the shore behavior at the profile area.

The mean tide range in the area is about 0.9 feet.

The profile monitor sites are at a bluff section about 50 feet in elevation, which intersects the shoreline about 150 feet northwest of the ravine cut. At the base of the ravine itself there is a low, wave-sculptured terrace. The profile layout consists of three transects spaced 30 feet apart. Typical profiles (October 1978) are shown in Figure 4.23 which also indicates the sites where sediment samples were acquired in April, 1979. Sediments were sampled from the beach in the upper 1-2 inches of the shoreline profiles and textural characteristics of the sediments are shown in Table 4.5. All the sediments at the study site are predominantly sand size, but the bluff and talus slopes contain a significant fraction of silt and clay. These fine-grained materials get winnowed out in the sorting process under wave action and are deposited in deeper waters offshore. As in the case of the bluff at Site B (on the upper South River near Goose Island), fragments of limonitic sandstone-type material litter the toe of the bluff on the shoreline profile. These fragments represent the lag material from successive slumps of the bluff face which remain after the sand and mud are redistributed by wave action.

Next pages: Figure 4.21 (left) Location Map showing Site D.

Figure 4.22 (upper right) Aerial view of Site D.
Figure 4.23 (lower right) Typical profile of Site D in October 1978.

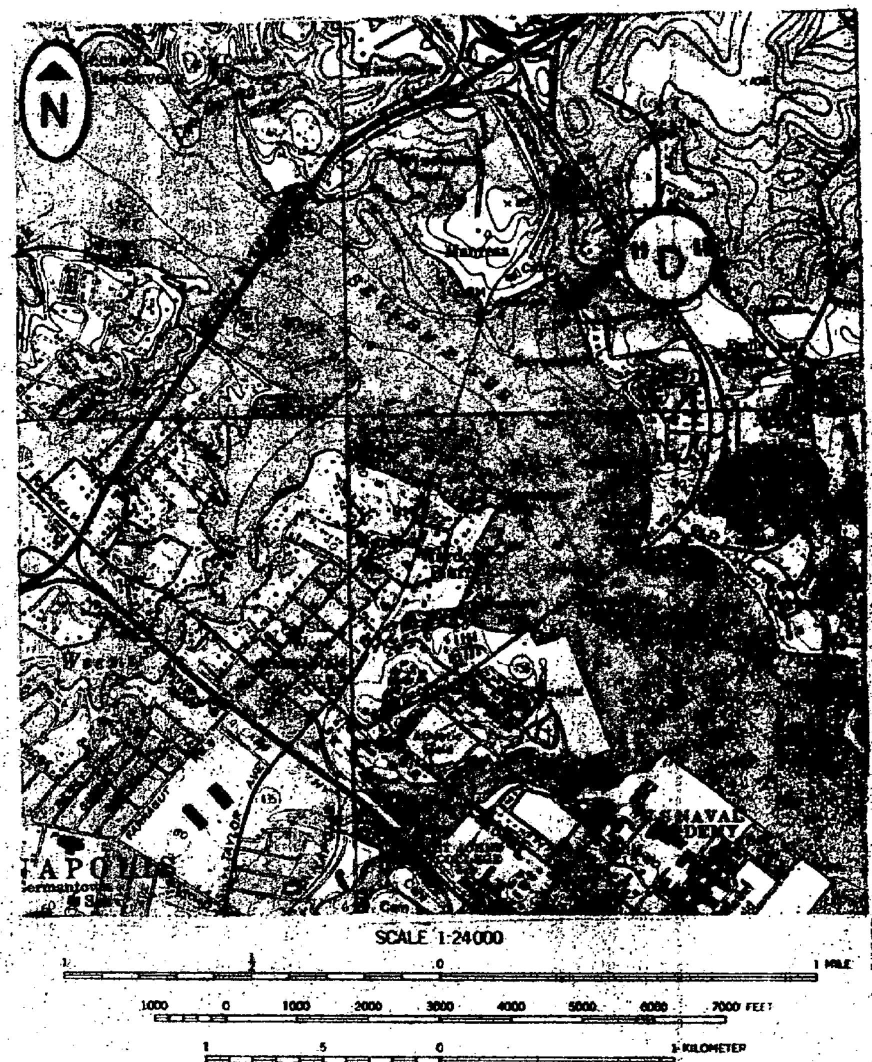

N
SCALE 1:24000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

Figure 4.21

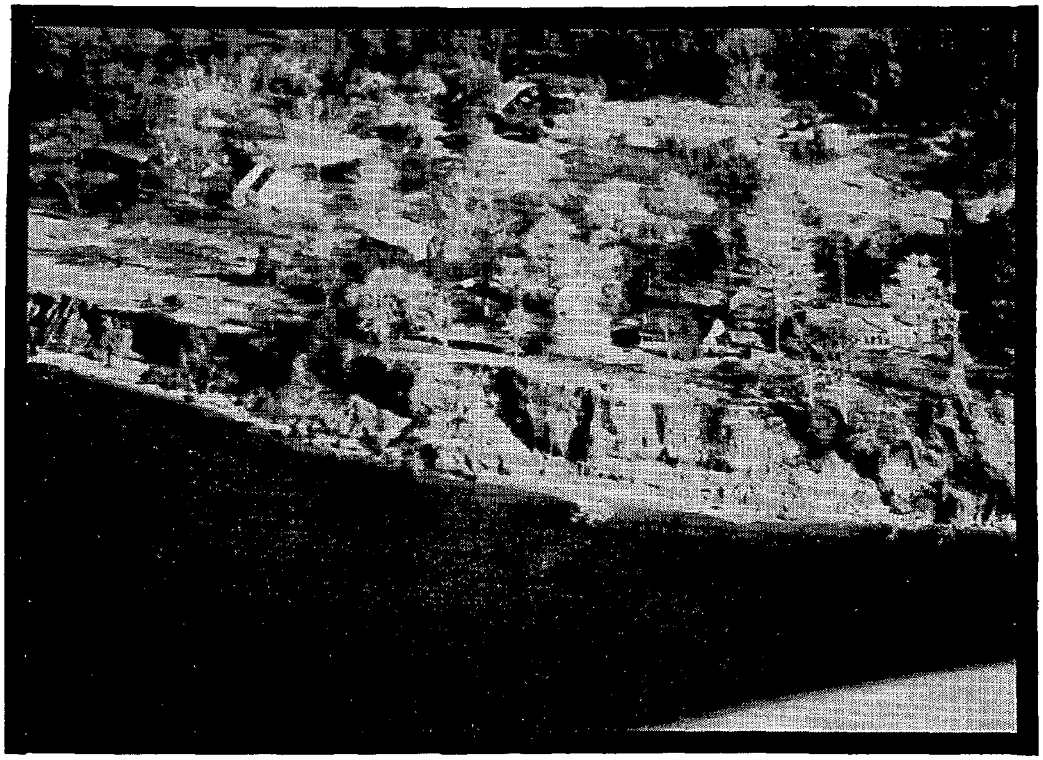


Figure 4.22

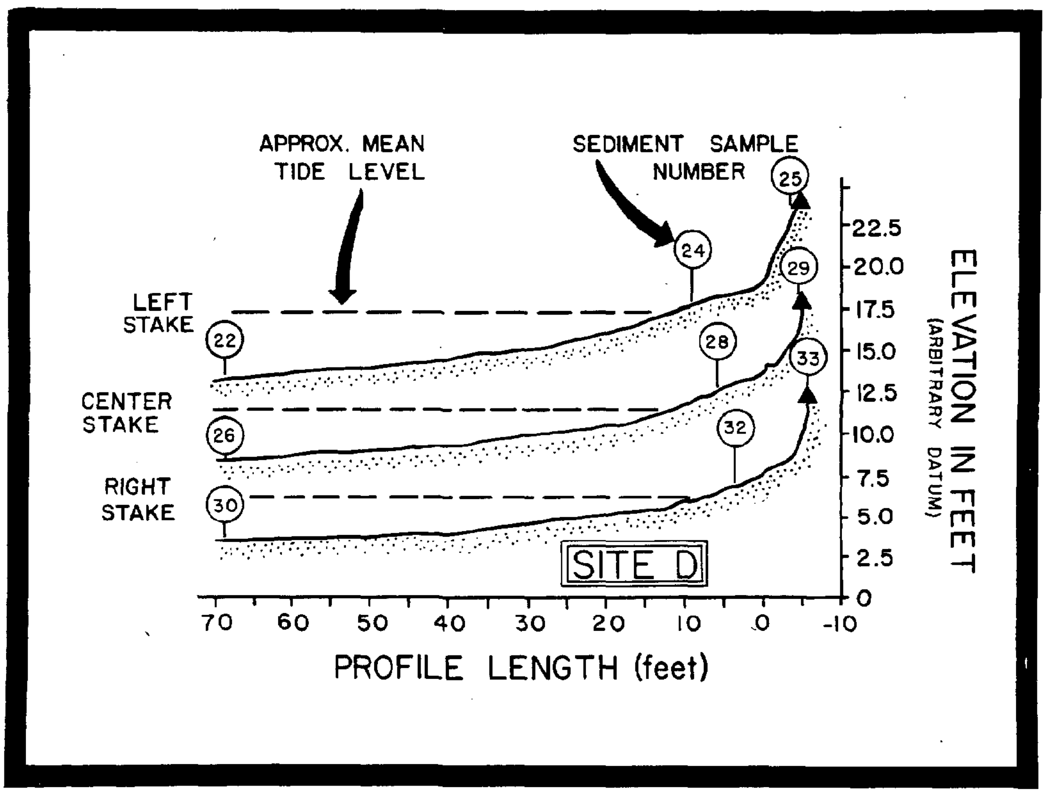


Figure 4.23

TABLE 4.5

SEDIMENT CHARACTERISTICS; SITE D

Sample No.	Profile	Distance From Origin	Zone	*Gravel (<2.0 mm)		Sand (0.062mm to 2mm)		Silt (0.0039 to 0.062mm)		Clay (<0.0039 mm)	
				Mineral	Organic	Mineral	Organic	Mineral	Organic	Mineral	Organic
33	Right	-4.8	Bluff Talus	9.74	-	61.95	1.65	9.26	0.53	14.04	2.83
32	Right	3.0	Foreshore	1.73	-	92.39	0.93	0.70	<0.01	2.63	1.62
30	Right	69.0	Offshore	1.86	-	91.42	0.92	0.88	0.09	2.91	1.92
29	Center	-5.7	Bluff Talus	7.66	-	80.31	0.57	2.10	0.12	7.41	1.83
28	Center	6.0	Foreshore	0.13	-	93.75	0.76	0.20	<0.01	3.45	1.71
26	Center	69.0	Offshore	0.67	-	89.53	0.90	0.46	0.42	5.89	2.12
25	Left	-3.0	Bluff Talus	1.62	-	86.59	1.05	2.59	0.03	6.01	2.11
24	Left	9.0	Foreshore	11.00	-	81.92	0.83	0.62	<0.01	4.12	1.51
22	Left	69.0	Offshore	3.61	-	86.61	0.87	0.97	0.31	5.77	1.85

*The numerical values shown represent the fractional weight, in grams, of 100 grams of sample, thus the results may also be interpreted as percentage values.

The beach at the study site receives boat-wake energy from boats travelling up and down the Severn River. Most of the boat traffic passes at distances greater than 1000 feet from the shoreline, but some localized boat traffic does pass closer to the shore and generates wakes which attack the shoreline profile. The boating characteristics at this site are discussed in Chapter VI.

This portion of the Severn River shoreline also receives wind waves which approach with the longest fetches from the northwest, south, and southeast. The wind-wave climate at this site is discussed in Appendix B and the wind waves and boat wakes are compared in Chapter VII for their relative importance in causing any changes in the shoreline profiles.

As in the case of the other bluff site (Site B), the fastland boundary was defined as either the consolidated sediments of the bluff or the loose material slumped from the bluff. The sequence of photographs shown in Figure 4.24 indicates that until some time after the July survey (07/29/79) the modifications of the fastland were, in fact, due to removal of slumped material. However the passage of Tropical Storm David in early September resulted in complete removal of the slumped material as well as erosion of the

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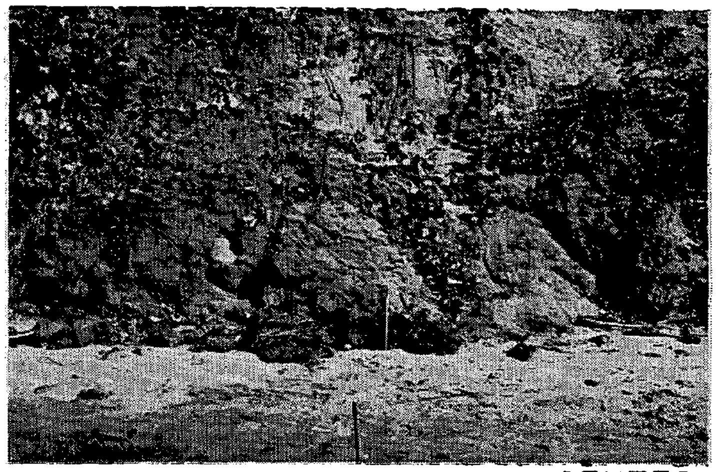
Opposite: Table 4.5 Sediment characteristics at Site D. The locations of the samples listed in the Table are shown on the profiles in Figure 4.23.

Next pages: Figures 4.24 a-d Photographic view of the three profile locations at Site D in October 1978, May 1979, July 1979, and October 1979.

RIGHT

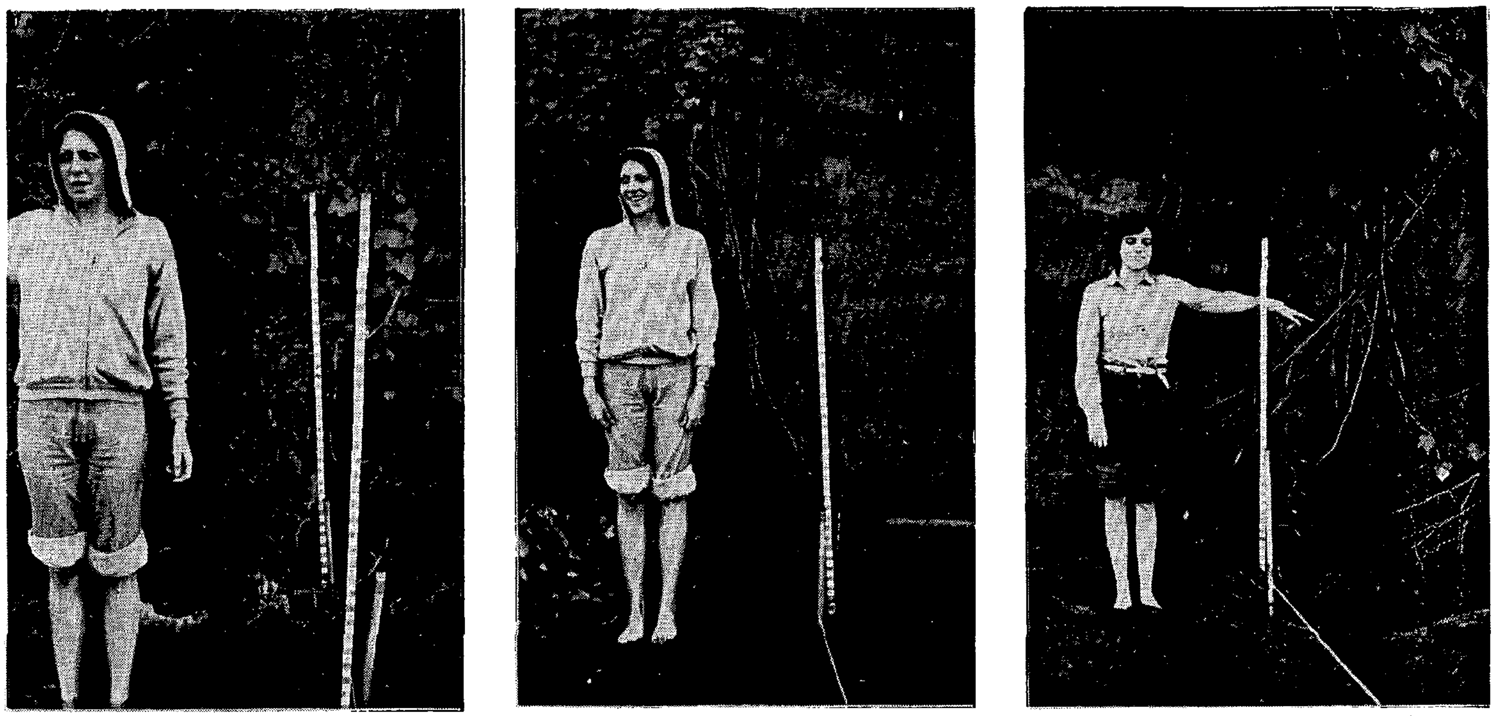


CENTER

LEFT

SITE "D" OCT. 1978

Figure 4.24a

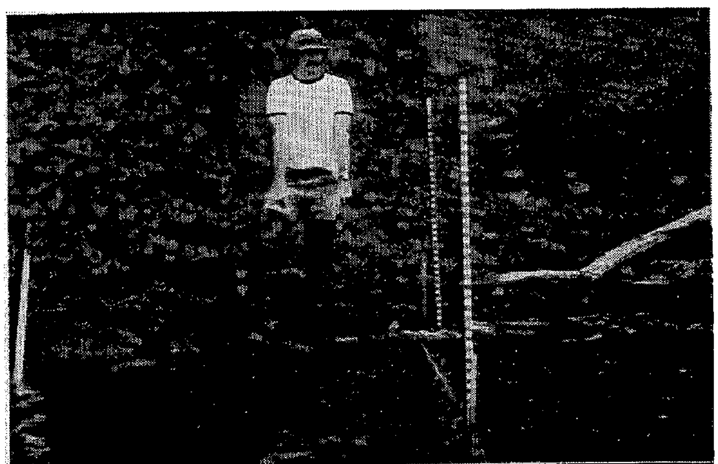


RIGHT CENTER LEFT

SITE "D" MAY 1979

Figure 4.24b

RIGHT



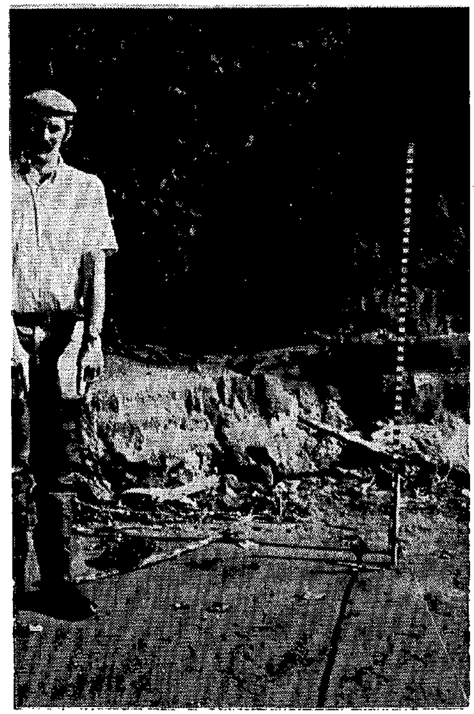
CENTER

LEFT

SITE "D" JULY 1979

Figure 4.24c


RIGHT


CENTER


LEFT

SITE "D" OCT. 1979

Figure 4.24d

consolidated bluff sediments. Thus in Figure 4.24d (October 1979) we see an exposed bluff (Left & Center) with a scarped terrace of sand in the backshore rather than slumped material.

The comparative envelopes of change between the periods of October 1978-May 1979, and May-October 1979, are shown in Figures 4.26 a and b, respectively. Note in particular that the surveys in June, July, and August cluster very close to the post-Tropical Storm David profiles of September and October 1979. The profile comparisons between successive months offer additional illustration that there was little profile modification during the peak boating season of June, July and August.

The details of the fastland modifications are shown in Figure 4.25 where sequential profile segments are displayed. At least two episodes of slumping occurred at the Left profile between the surveys of November 1978 and that of May 1979. Intervening surveys show reduction of the slumped material. Between the May and June surveys some additional reduction of slumped material (talus) occurred, but during the period of June through August the profiles were virtually identical. While the close similarity in monthly profile positions on this dynamic shoreline does not necessarily mean there has been no significant change in the time between profiles, there is little likelihood that the slump surface angles would be similar if there had, in fact, been significant changes between profile dates. Thus, these profiles are interpreted as showing no significant changes.

The storm surge associated with the passage to Tropical Storm David was about 2.5 feet, as determined from strand lines at the sites. This elevation at Site D, along with large wave heights (estimated up to 2-3 ft. by local observers) was sufficient to cause direct attack on the bluff as well as to reduce the volume of earlier slumped material. The comparative profiles of August and September 1979 (Figure 4.25) show a displacement of the fastland of 2.5 feet, part of which is bluff-face retreat. These profiles also show that the sand beach following David was considerably higher in elevation, and both the photographic evidence and the post-David survey of September show a scarped beach backshore. Thus between the first and third week of September 1979, Tropical Storm David eroded the bluff which resulted in a pronounced thickening of the beach sands, and this, in turn, was followed by a reduction in beach elevation as evidenced by the backshore sand scarp shown in Figures 4.24d and 4.24b.

The profile histories at the Center and Right profiles exhibit essentially the same patterns of behavior as previously discussed at the left profile: slumps reduced by

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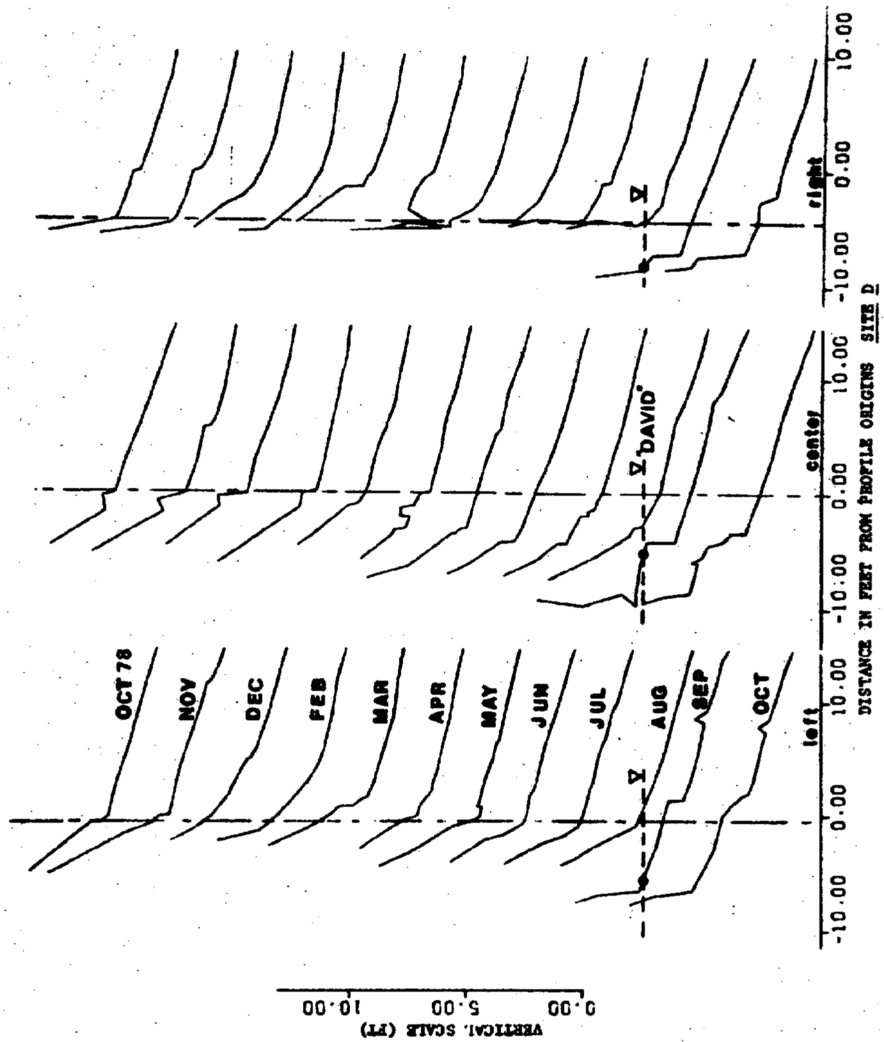
Next pages: Figure 4.25 (left) Profile comparisons between successive months at Site D.

Figure 4.26a (upper right) Profile overlay for Site D from October 1978 to May 1979.

Figure 4.26b (lower right) Profile overlay. for Site D from May 1979 to October 1979.



OCT 78
NOV
DEC
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
"DAVID"
left
center
right
-10.00
0.00
10.00
DISTANCE IN FEET FROM PROFILE ORIGINS
SITE D
0.00
5.00
10.00
VERTICAL SCALE (FT)

Figure 4.25

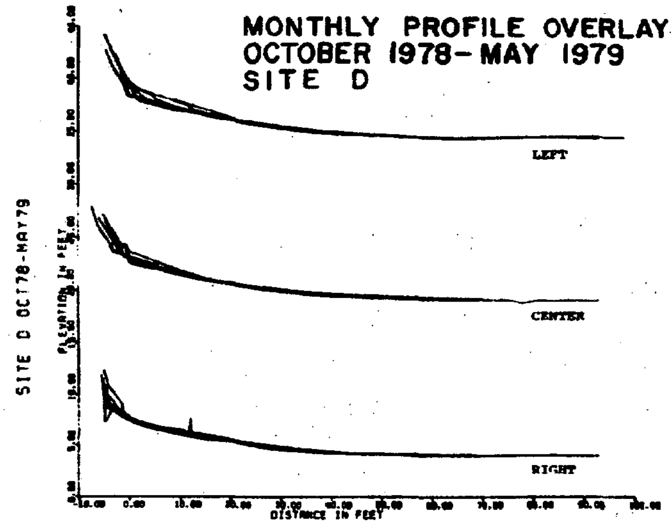


Figure 4.26a

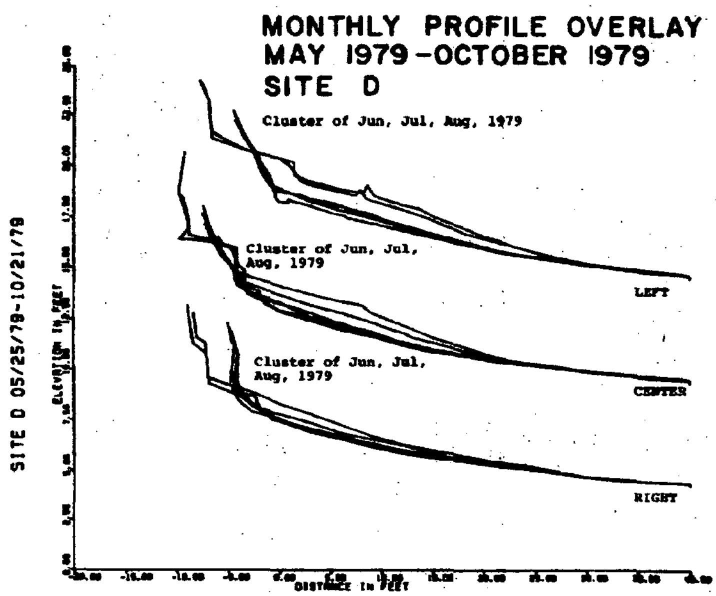


Figure 4.26b

wave action during the late fall, winter, and early spring; relative quiescence during the peak boating season of June, July, and August. The occurrence of Tropical Storm David with a large storm surge and large waves from the southeast dominated the profile response.

In summary, the observations over the one-year period demonstrated the role of wind waves in the reduction of the material eroded from face of the bluffs. But the most important effect was a single storm event, with a large storm surge and waves that dominated the fastland and shore zone response over an annual cycle. Finally, it should be noted that the profile modifications during the boating season, aside from the storm response, were very small relative to the changes during the non-boating season.

Site E. A pocket marsh near the entrance of Maynedier Creek off of the upper Severn River.

This site, located near the mouth of Maynedier Creek (Figs. 4.27, 4.28, 4.29) is a ravine-mouth marsh, approximately 175 ft. in width across the frontal margin. The marsh is predominantly clump growths of Spartina cynosuroides and Scirpus sp. which are tightly bound by root mass and soil, and virtually "float" on a substrate of very soft organic "mush". While a "shaky" "firm" footing may be found on the clumps, a misstep leaves the observer knee-high "in the mush". The shoreline on the flanks of the marsh intersects a thin veneer of sand overlying a plastic tan clay which also forms the steep banks with an elevation of about 4 feet. The nearshore (and offshore) fronting the marsh itself is a very soft substrate varying between sandy-silt to silty-clay The organic content of samples collected along the shoreline profiles is high (Table 4.6).

The mean tide range is about 0.8 feet. There are no shoreline protection structures influencing the area.

The marsh receives boat-wake wave energy from boats

Next pages: Figure 4.27 (left) Location map showing Site E.

Figure 4.28 (upper right) Aerial view of Site E.

Figure 4.29 (lower right) Typical profile of Site E in October 1978.

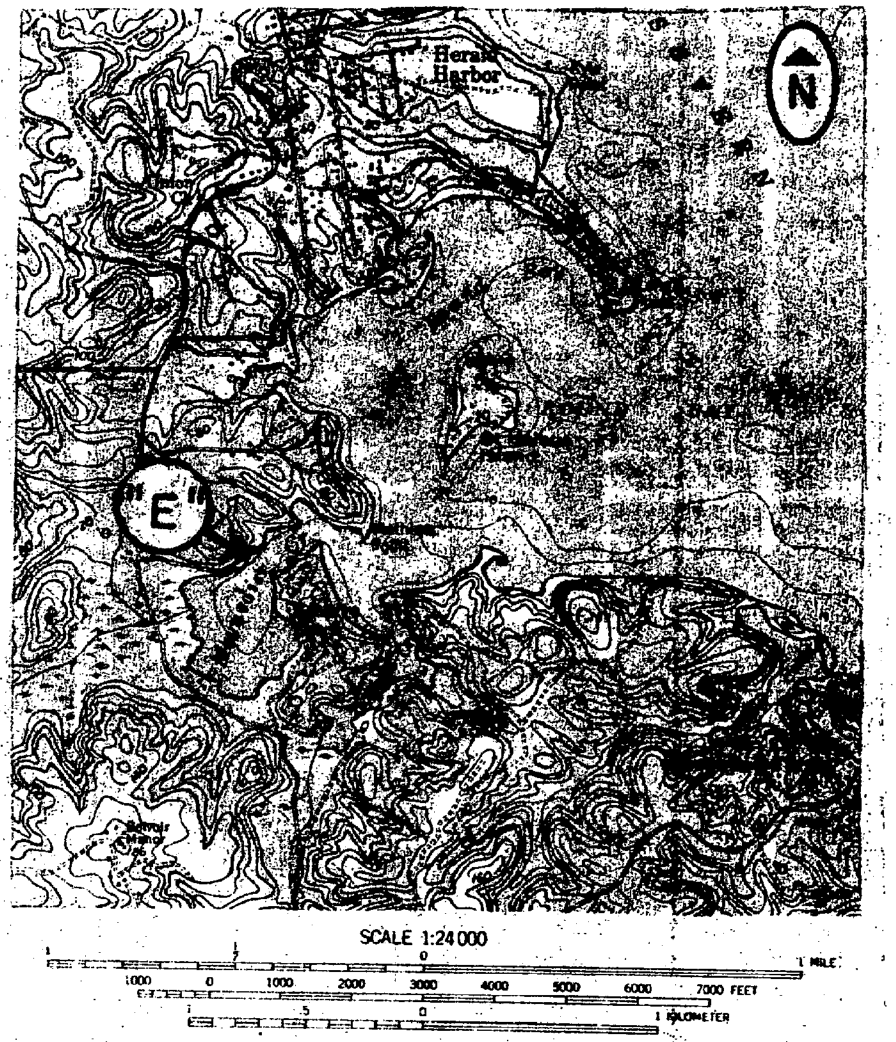

Herald Harbor
N
"E"
SCALE 1:24000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER

Figure 4.27

Figure 4.28

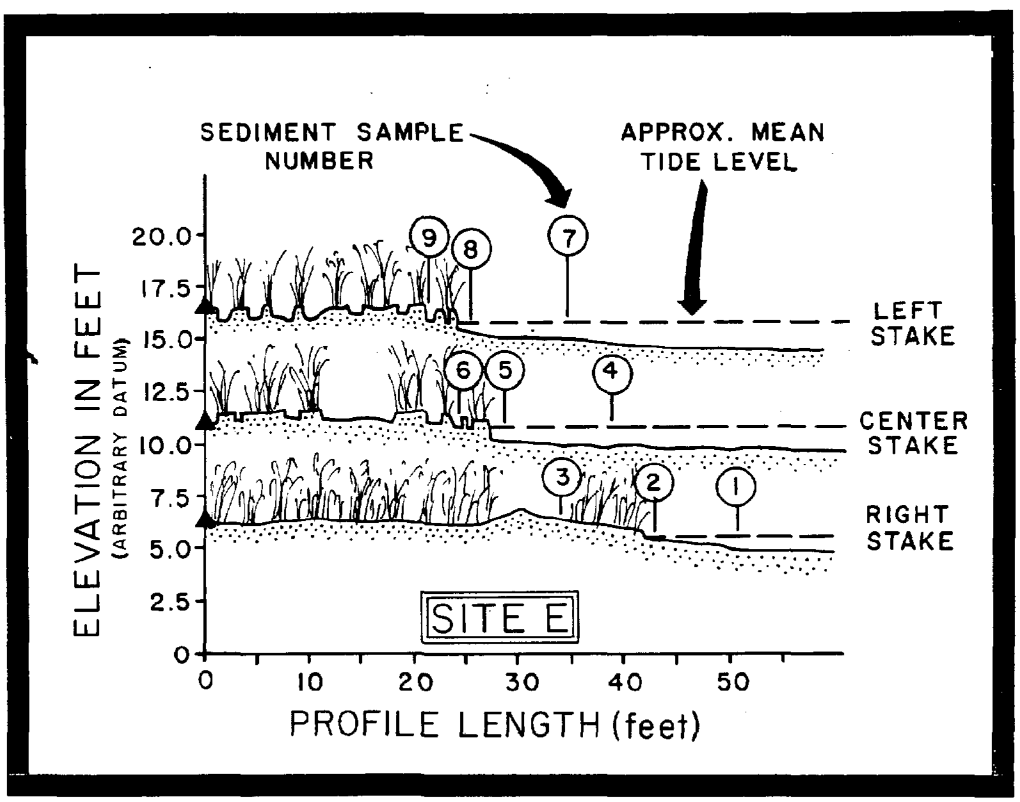


Figure 4.29

Table 4.6

SEDIMENT CHARACTERISTICS; SITE E

Sample No.	Profile	Distance From Origin	Zone	*Gravel (<2.0 mm)	Sand (0.062mm to 2mm)		Silt (0.0039 to 0.062mm)		Clay (<0.0039 mm)	
					Mineral	Organic	Mineral	Organic	Mineral	Organic
BD3	Right	34.0 ft.	Marsh	0.97	93.02	0.94	2.06	0.22	0.83	1.96
BD2	Right	36.0	Foreshore	1.00	96.04	0.19	0.06	0.87	0.37	1.47
BD1	Right	51.0	Nearshore	6.08	65.35	3.37	10.59	2.00	9.23	3.38
BD6	Center	25.0	Marsh	8.09	32.17	14.86	19.76	3.13	12.95	9.03
BD5	Center	28.0	Foreshore	7.41	34.50	12.96	19.80	1.88	12.92	10.52
BD4	Center	39.0	Nearshore	4.23	44.93	6.18	27.58	2.02	8.01	7.04
BD9	Left	19.0	Marsh	6.81	29.81	24.79	17.77	2.91	7.24	10.67
BD8	Left	26.0	Foreshore	10.71	41.52	15.28	14.87	1.99	7.74	7.89
BD7	Left	36.0	Nearshore	6.79	47.65	8.15	20.06	1.50	8.36	7.48

*The numerical values shown represent the fractional weight, in grams, of 100 grams of sample, thus the results may also be interpreted as percentage values.

entering and leaving Maynedier Creek. There is a posted speed-control zone in the creek on weekends. Boats travelling near the study site commonly pass within a few hundred feet from the shoreline. The boating characteristics at this site are discussed in more detail in Chapter VI.

The entrance to Maynedier Creek is relatively protected from heavy wave action by Mathiers Point and the shallow bathymetry of Round Bay to the east. The limited fetch within Maynedier Creek (maximum about 2,000 ft. to the south) precludes any significant wind-wave generation within the area.

The wind-wave climate at this site is discussed in Appendix B, and the wind waves and boat wakes are compared in Chapter VII for their relative importance in causing any changes in the shoreline profiles.

Three profile stations, 30 feet apart, are established on the frontal face of the marsh. Typical profiles (October 1978) are shown in Figure 4.29. Repetitive profiling and visual observation between October 1978-February 1979 indicated little or no change in the marsh behind the shore. After February, auxillary profile stakes were emplaced to

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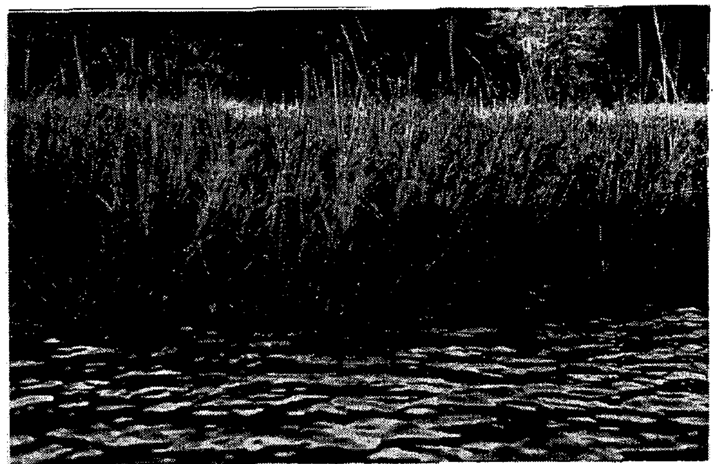
Opposite: Table 4.6 Sediment characteristics at Site E. The location of the samples listed in the Table are shown on the profiles in Figure 4.29.

Next pages: Figures 4.30 a-d Photographic view of the three profile locations at Site E in October 1978, May 1979, August 1979, and October 1979.



CENTER

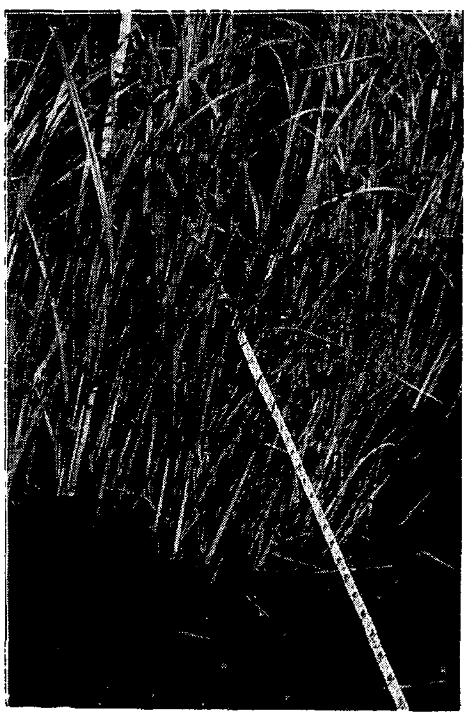
RIGHT

LEFT

SITE "E" OCT. 1978

Figure 4.30 a

LEFT

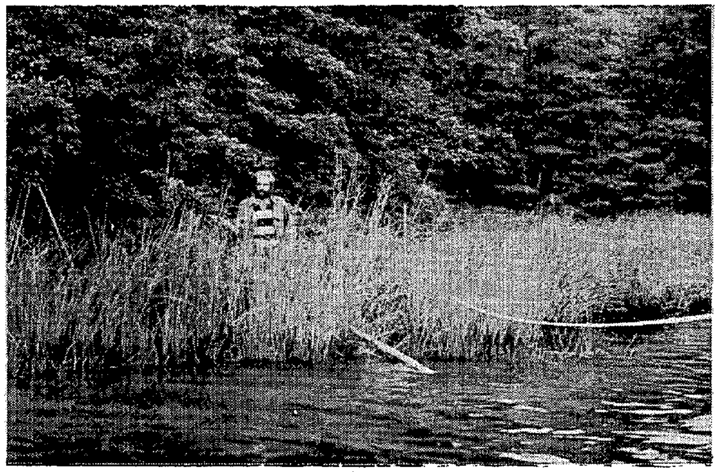


CENTER

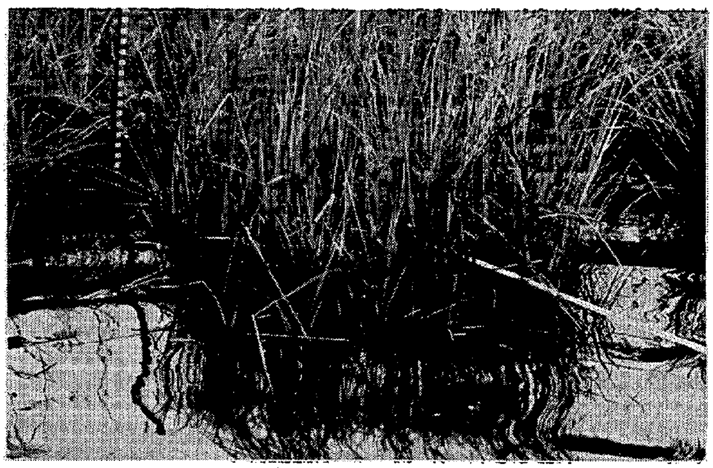
RIGHT

SITE "E" MAY 1979

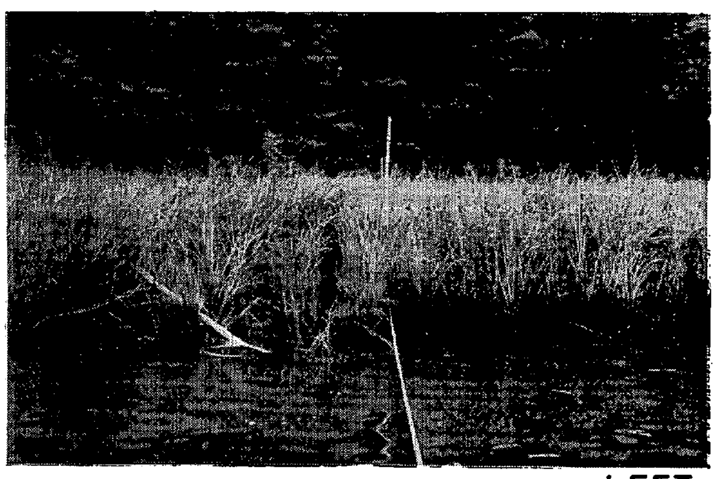
Figure 4.30b



RIGHT



CENTER

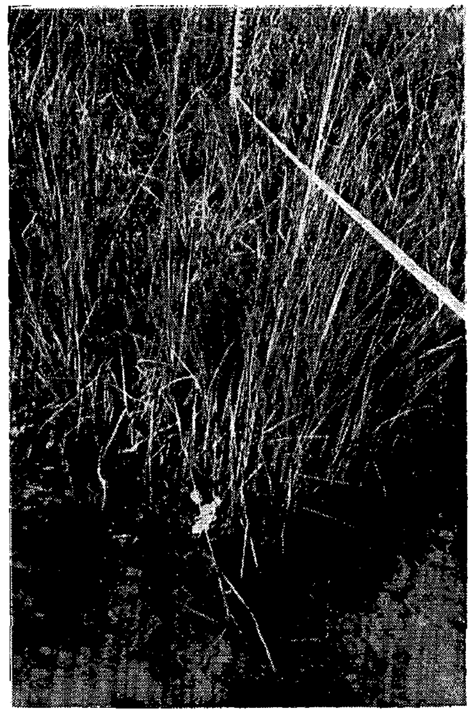


LEFT

SITE "E" AUG. 1979

Figure 4.30c

RIGHT



CENTER

LEFT

SITE "E" OCT. 1979

Figure 4.30d

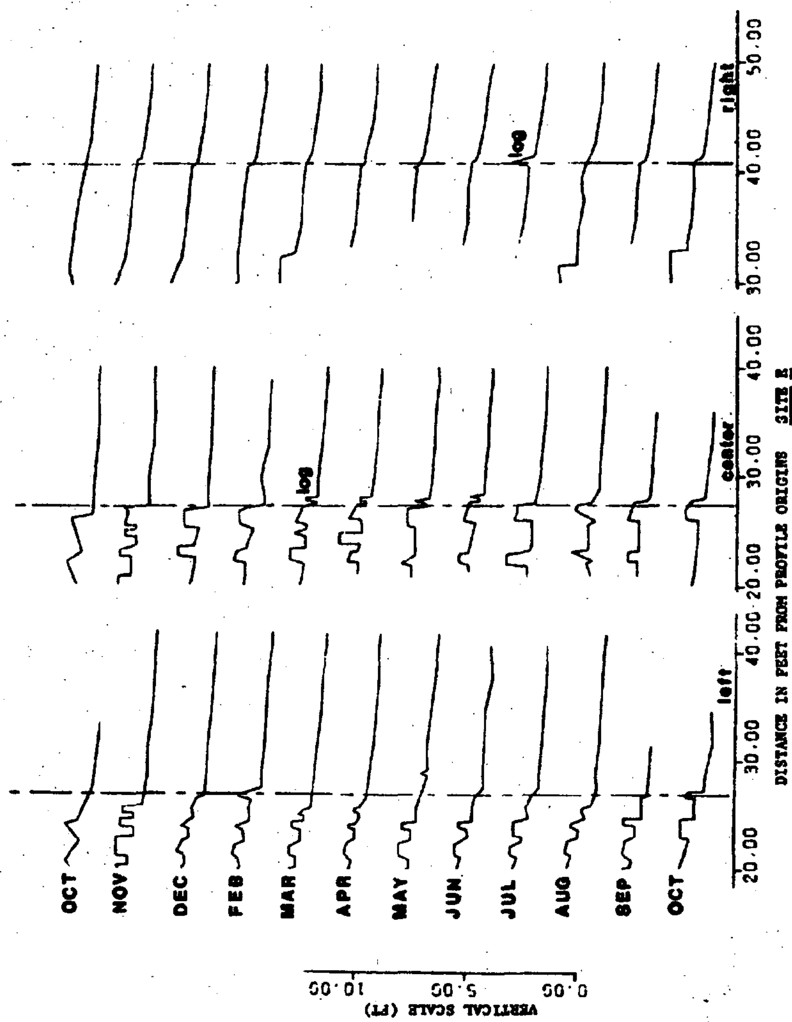
minimize observer disturbance to the marsh system. The edge of the marsh vegetation was considered to be the fastland boundary. The series of photographic observations and the profile surveys shown below indicate there was no fastland retreat during the one year observation period. The photographic series (October 1978; May, August, October 1979) are shown in Figure 4.31 and the profile envelopes for October 1978-to-May 1979, and May-to-October 1979 are shown in Figure 4.32. The difficulties of surveying in a marsh composed of isolated, irregularly shaped clumps of vegetation are exemplified in the two sets of profile overlays. The measurement of the exact position of the fastland edge varied with the tightness of the measuring tape, and the precision of the rodman staying "on line". The tape tightness necessarily varied with the height and density of vegetation while straying off line could result in missing the edge of a marsh clump. This is best illustrated in Figure 4.30c (Left) where it is to be noted that the tape passes just to the side of a marsh segment. Positioning the tape slightly different would result in the inclusion of the marsh segment in the profile. In the Left profile sequence of Figure 4.31 this was the case in the surveys of February and October 1979.

In summary, the monthly photography provides unambiguous decumentation that there was no measurable retreat of the marsh edge on the Left profile. The profile sequence in Figure 4.31 for the Center and Right profiles demonstrate that there was no change at these two profiles either.

Next pages: Figure 4.31 (left) Profile comparisons between successive months at Site E.

Figure 4.32a (upper right) Profile overlay for Site E from October 1978 to May 1979.

Figure 4-32b (lower right) Profile overlay for Site E from May 1979 to October 1979.



OCT
NOV
DEC
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
left
center
right
log
log
20.00
30.00
40.00
20.00
30.00
40.00
30.00
40.00
50.00
DISTANCE IN FEET FROM PROFILE ORIGINS SITE E
VERTICAL SCALE (FT)
0.00
5.00
10.00

Figure 4.31

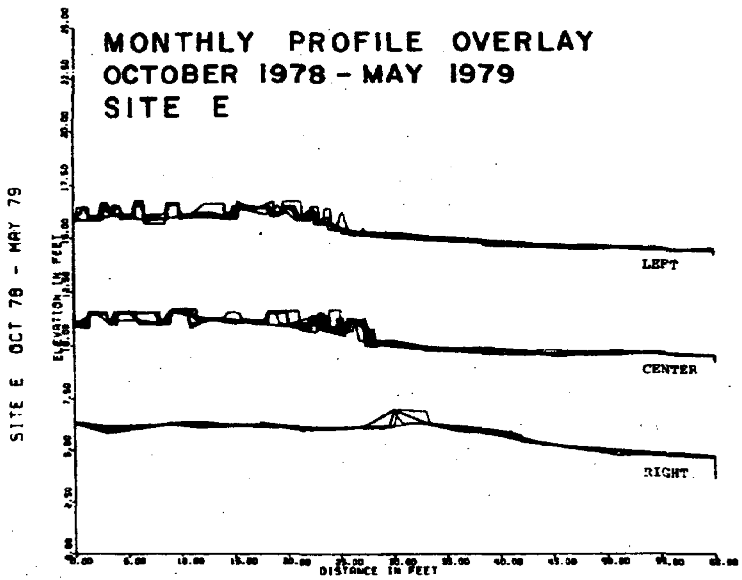


Figure 4.32a

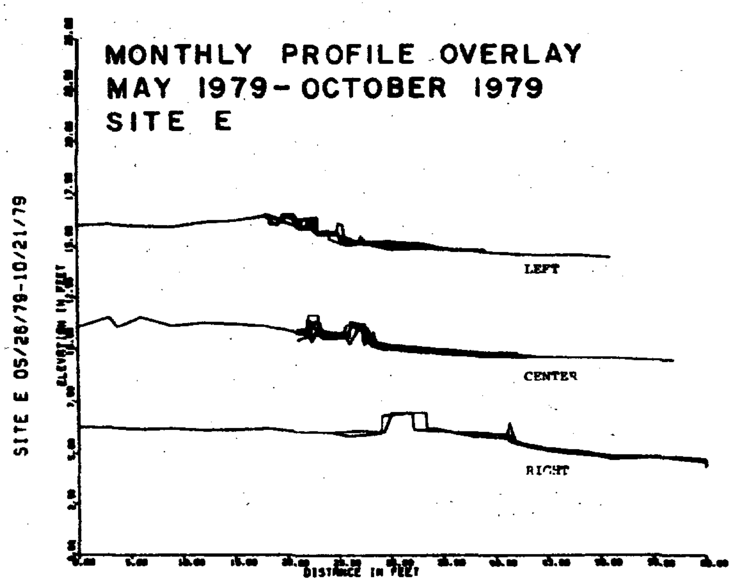


Figure 4.32b

V

BEHAVIOR OF SHORELINE PROFILES AT ADDITIONAL SITES

Michael Perry, Deborah Blades,
Rhonda Waller, and Tristina Deitz

A. Introduction

In addition to those sites described in the last chapter, additional sets of monthly profiles were collected by DNR student interns from the Environmental Studies Program at Anne Arundel Community College. Some of these supplemental sites were adjacent to the consultants' profiling locations and represented different shoreline types, (i.e. a marsh next to a bluff, or a bank next to a marsh). The supplemental sites also included two additional locations which were initially selected as "back-up" sites to the consultants' locations, and were to be used in the event that boating patterns at one of the principal sites turned out not to be as anticipated.

The results presented in this chapter show Tropical Storm David produced the greatest changes in shoreline profiles. Some other sediment movement was measured during the year of study, but no important changes at any of the sites took place during the boating season.

B. Methods

At each of the sites, three profiling locations were selected with a separation distance of 30 feet. Each profile was established by inserting two reference pipes or stakes several feet apart on a line perpendicular to the beach or shoreline. The position of the six reference pipes was then surveyed from a fixed bronze survey marker set in concrete with a transit and rod.

When the shoreline profiles were surveyed each month, the ground elevations along each profile were referenced to that of the benchmark using a precision level and rod. The rear reference pipe was considered to be the origin for each profile. The ground elevations were surveyed at 3-foot intervals, and at all additional intermediate points where a slope change occurred. At the three sites with banks or bluffs (Sites AA, CC, EE), the profiles were extended up the bluff face from the rear stakes, and elevations were surveyed at intervals up to the instrument height.

Site AA: A pocket marsh and adjacent bluff in Harness Creek off the lower South River.

This site is located in an area known as Hillsmere Shores (Figure 5.1.) The beach segment chosen for

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Next pages: Figure 5.1 (left) Location map showing Site AA.

Figure 5.2 (upper right) Aerial view of Site AA.

Figure 5.3 (lower right) Typical profile of Site AA in October 1978.

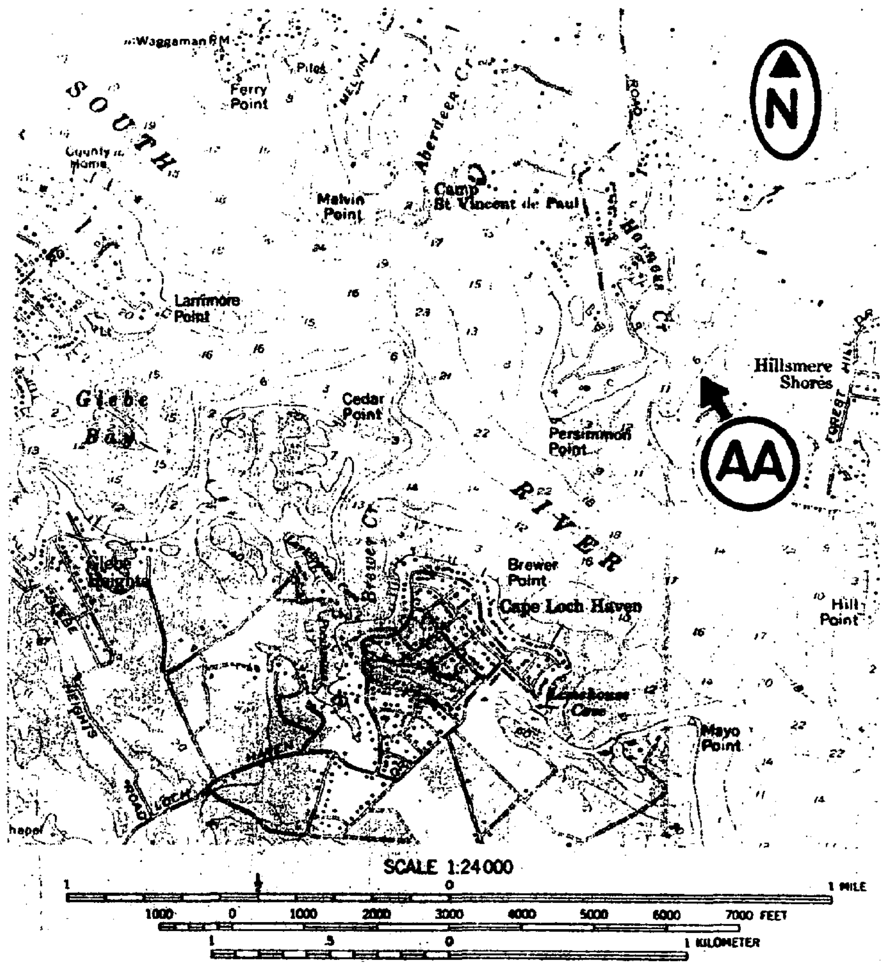

N
SOUTH
RIVER
Ferry Point
Malvin Point
Camp St Vincent de Paul
Aberdeen Cr
Larrimore Point
Glebe Bay
Cedar Point
Persimmon Point
Hillsmere Shores
AA
Brewer Point
Cape Loch Haven
Hill Point
Mayo Point
SCALE 1:24 000
1 MILE
7000 FEET
1 KILOMETER

Figure 5.1

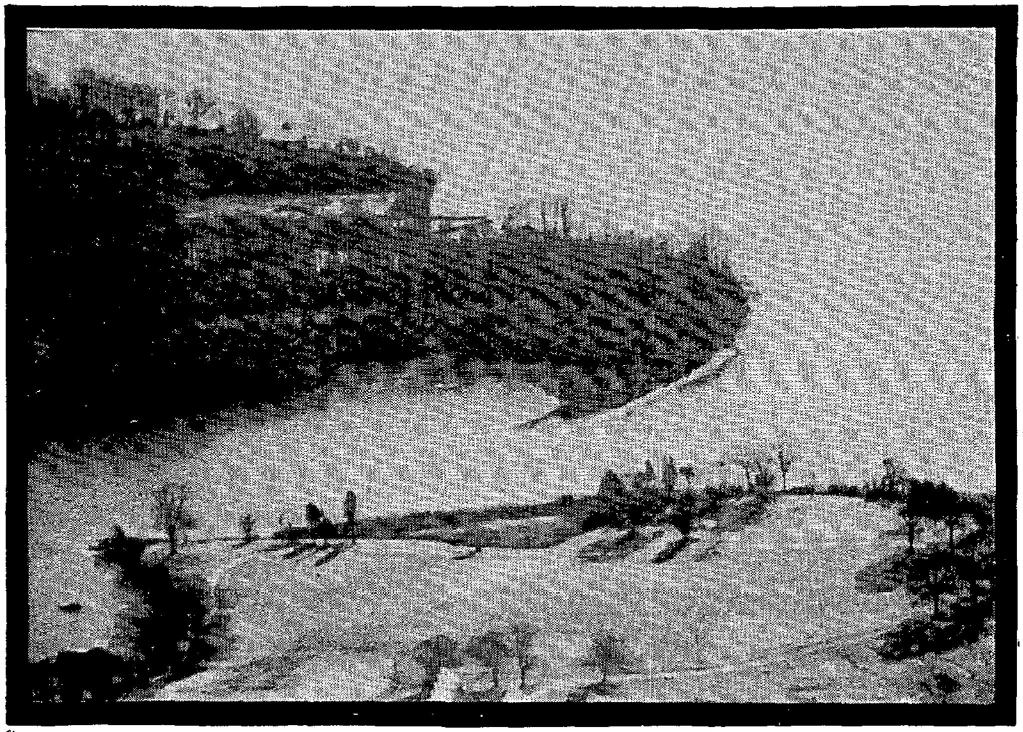


Figure 5.2

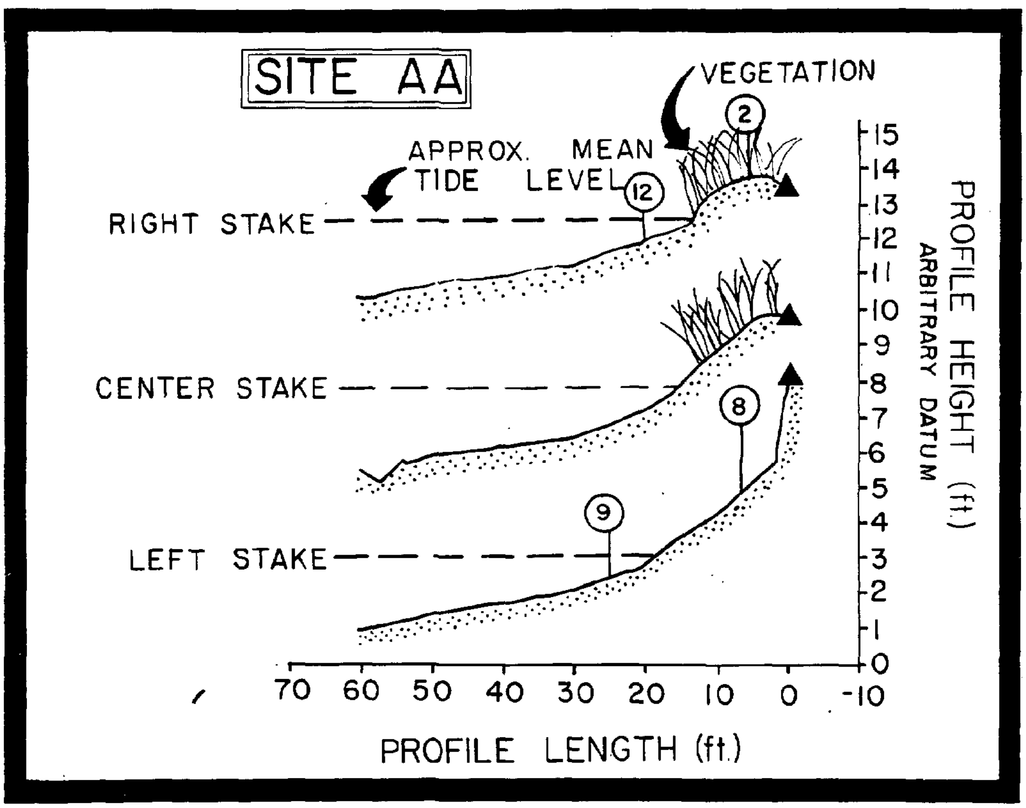


Figure 5.3

TABLE 5-1 SEDIMENT CHARACTERISTICS

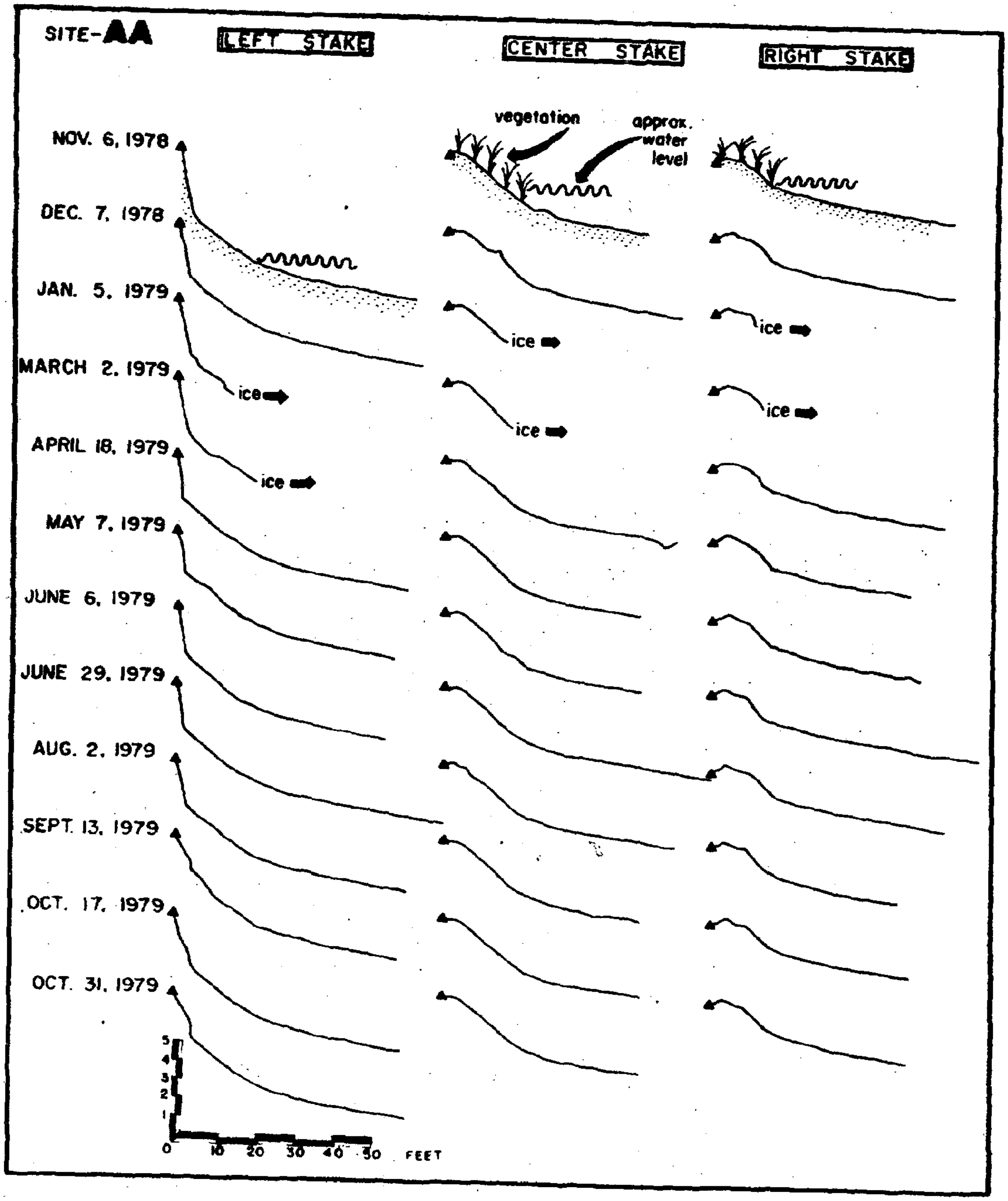
SITE	PROFILE	SAMPLE	DISTANCE FROM ORIGIN	ZONE	% SAND	% SILT PLUS CLAY
AA	LEFT	2	0 ft.	BLUFF TALUS	70%	30%
AA	LEFT	12	20 ft.	OFFSHORE	80%	20%
AA	RIGHT	8	5 ft.	MARSH	98%	2%
AA	RIGHT	9	25 ft.	OFFSHORE	89%	11%
BB	RIGHT	6	3 ft.	MARSH	99%	1%
BB	LEFT	17	3 ft.	OFFSHORE	90%	10%
BB	LEFT	11	26 ft.	OFFSHORE	88%	12%
CC	LEFT	4	5 ft.	BLUFF	76%	24%
CC	LEFT	16	15 ft.	OFFSHORE	95%	5%
CC	RIGHT	13	8 ft.	NEARSHORE	99%	1%
CC	RIGHT	14	18 ft.	OFFSHORE	95%	5%
EE	RIGHT	1	12 ft.	BLUFF TALUS	70%	30%
EE	RIGHT	15	28 ft.	OFFSHORE	93%	7%
EE	RIGHT	5	17 ft.	NEARSHORE	98%	2%
FF	RIGHT	3	15 ft.	FORESHORE	97%	3%
FF	LEFT	10	10 ft.	MARSH	66%	34%
FF	LEFT	7	20 ft.	OFFSHORE	98%	2%

monitoring is on the southern shore of Harness Creek in an area where a bluff meets with a pocket marsh formed at the mouth of a ravine. Site AA is in the vicinity of the consultants' profile site Site A, which was discussed in the previous chapter.

The profile layout for site AA consisted of 3 transects spaced 30 feet apart. The right and center profiles are located on the marsh, which extends approximately 300 feet across its frontal margin and about 200 feet inland. The left profile is located at the base of the adjacent bluff which is approximately 10 feet high.

The vegetation at the right and center profiles consists of marsh grasses growing in thick compact clumps. The marsh grass ends at the shoreline in a sharp boundary. The bluff face on the left profile is largely exposed eroding sediments. At the top of the bluff are mature trees, shrubs, and vines which extend up to the bluff face. The bluff is nearly vertical in the upper portions and covered with exposed root masses. A number of trees have fallen over the bluff edge onto the beach; the entire shoreline surrounding the study site is littered with fallen trees and driftwood.

Opposite: Table 5.1 Sediment characteristics at the additional study sites. The locations of the samples listed in the Table are shown on the profiles in Figures 5.3, 5.7, 5.11, 5.15, and 5.19.



SITE-AA
LEFT STAKE
CENTER STAKE
RIGHT STAKE
vegetation
approx. water level
NOV. 6, 1978
DEC. 7, 1978
JAN. 5, 1979
MARCH 2, 1979
APRIL 18, 1979
MAY 7, 1979
JUNE 6, 1979
JUNE 29, 1979
AUG. 2, 1979
SEPT. 13, 1979
OCT. 17, 1979
OCT. 31, 1979
ice
FEET

Figure 5.4

Sediment samples were collected from the beach and nearshore in the upper 1-2 inches of the shoreline profiles (Table 5.1). The sediments in the nearshore at site AA are principally derived from the erosion of the bluff. Table 5.1 shows the bluff sediments contain about 30% silt and clay. The nearshore sample contains a similar portion of fine-grained material. The samples collected in front of the marsh and nearshore contained slightly less silt and clay than the offshore samples.

The mean tide range in the area is approximately 1.0 foot, and there were no shoreline structures present along the reach during the period of study.

The shoreline at site AA receives boat-wake energy mainly from boats entering and exiting Harness Creek. Much of the boat traffic near the study site stays within the main channel which is approximately 500-1000 feet from the profile locations.

The shoreline of site AA also receives wind-wave energy mainly from the northwest. Normal winds from any other direction produce small waves at the site.

The fastland boundary for the bluff at the left profile stake was defined as either the inplace semi-consolidated sediments forming the bluff or the material which slumped from the bluff face. The reason for considering the slumped material as fastland is that were it not for the removal of

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<u>Opposite:</u> <u>Figure 5.4</u> Comparison of monthly profiles collected at Site AA.

this material by wave action, the bluff slope would ultimately reduce and become stabilized with vegetation. The fastland boundaries for the center and right stakes were defined as the edge of vegetation. These boundaries are composed of the compact root masses of the marsh grass.

Profiles at site AA were collected monthly, and a comparison between successive months is illustrated in Figure 5.4. This comparison of successive profiles shows that the bluff located at the left stake experienced modulation of sediments and fastland retreat. The right and center stakes located in front of the marsh showed no important changes during the year of study, in either the boating or non-boating seasons.

There are noticeable changes in the amounts of material which have accumulated at the base of the bluff on profiles in January, April,and September of 1979 (Figure 5.4). This material is usually reduced by the next profile date. These modulations of sediments on the profiles are thought to be due to slumping and subsequent wave action washing out the slumped material. The boating season was considered to start in May of 1979, and some of the slumped material from the previous month's profile at the left stake is still noticeable at the base of the bluff. This material decreases slightly during the summer. In September of 1979, the storm surge during Tropical Storm David focused wave action directly on the bluff face at the left profile stake, and more material accumulated at the base of the bluff on the shoreline profile taken after David. Some reduction of the talus deposit occurred between the September and October profiling dates, but the profile at the left stake was slightly built up again by the end of October. The near-shore portion of the profiles at the left stake show a slight accumulation of material until September 1979, when David came through the area.

In summary, Tropical Storm David was accompanied by the greatest change in shoreline profiles at this site. These changes occurred in front of the bluff, where the slumped material on the beach was eroded. Smaller changes in this portion of the shoreline profile also were observed earlier in the study period. The two adjacent profiles in the adjoining marsh showed no change in either the boating on non-boating seasons.

Site BB: A pocket marsh on the upper South River near Goose Island

This site is located near the Glen Isle subdivision on the southern shore of the upper South River (Figure 5.5). The shoreline segment chosen for monitoring is a small pocket marsh 750 feet downstream from the mouth of Flat

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Next pages: Figure 5.5 (left) Location map showing Site BB.

Figure 5.6 (upper right) Aerial view of Site BB.

Figure 5.7 (lower right) Typical profile of Site BB in October 1978.

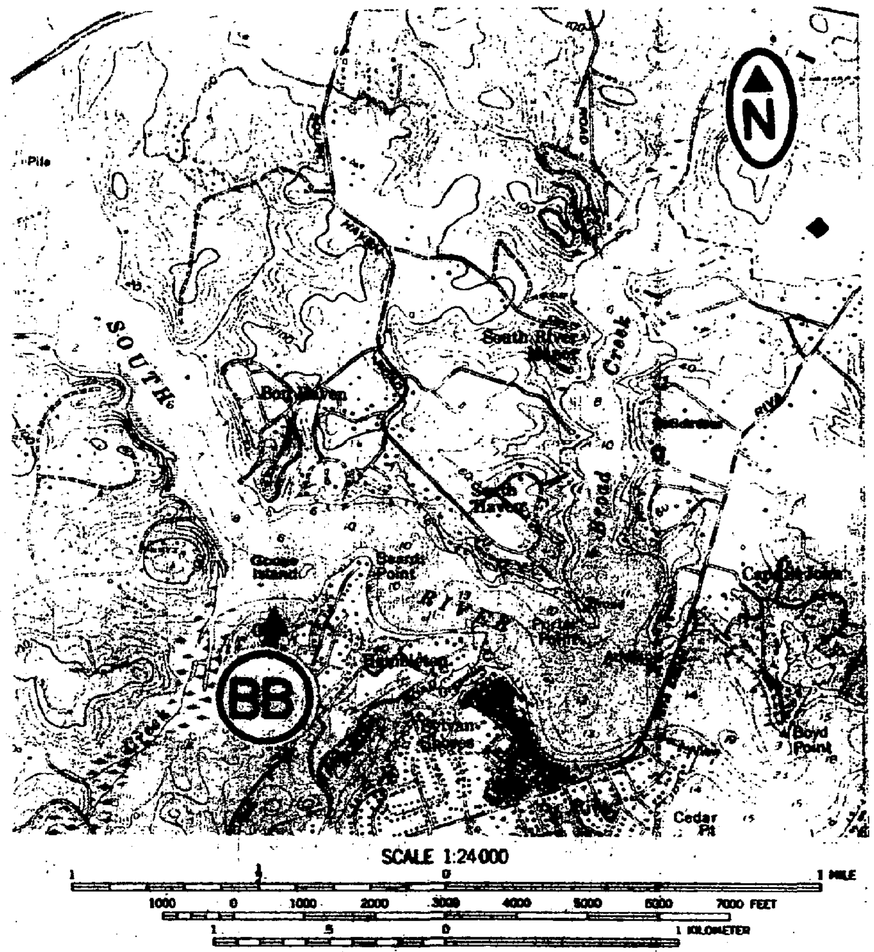


Figure 5.5

5-11

Figure 5.6

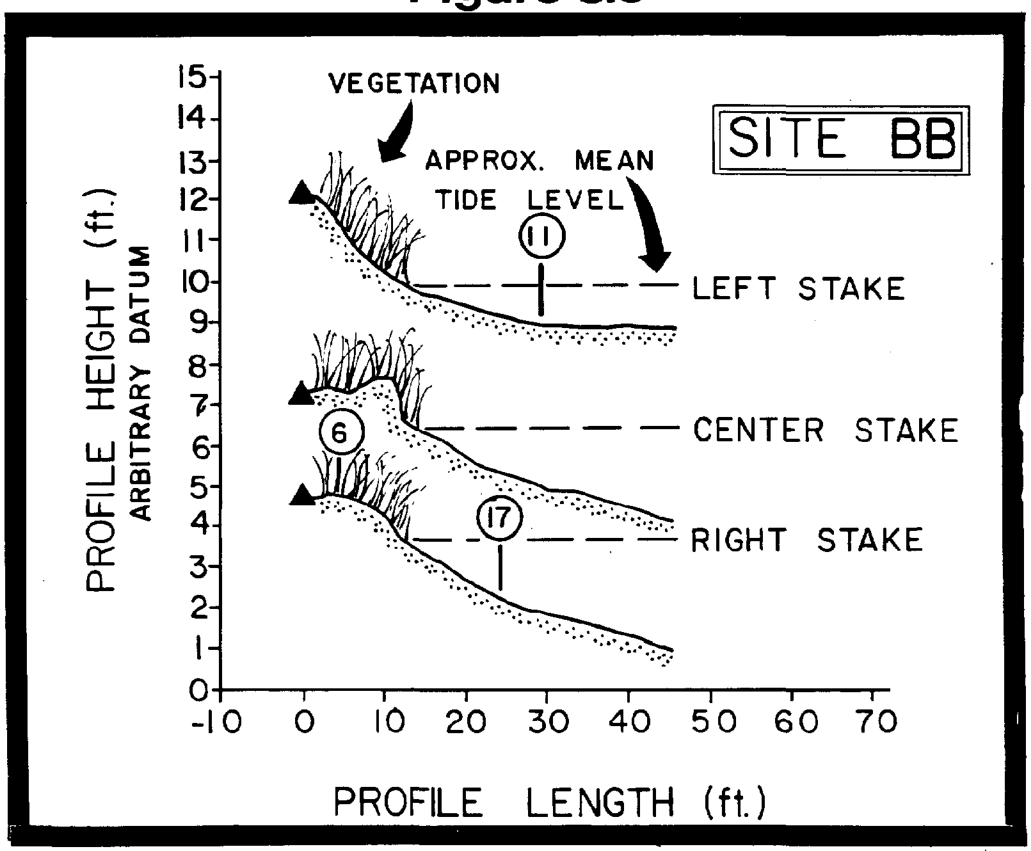
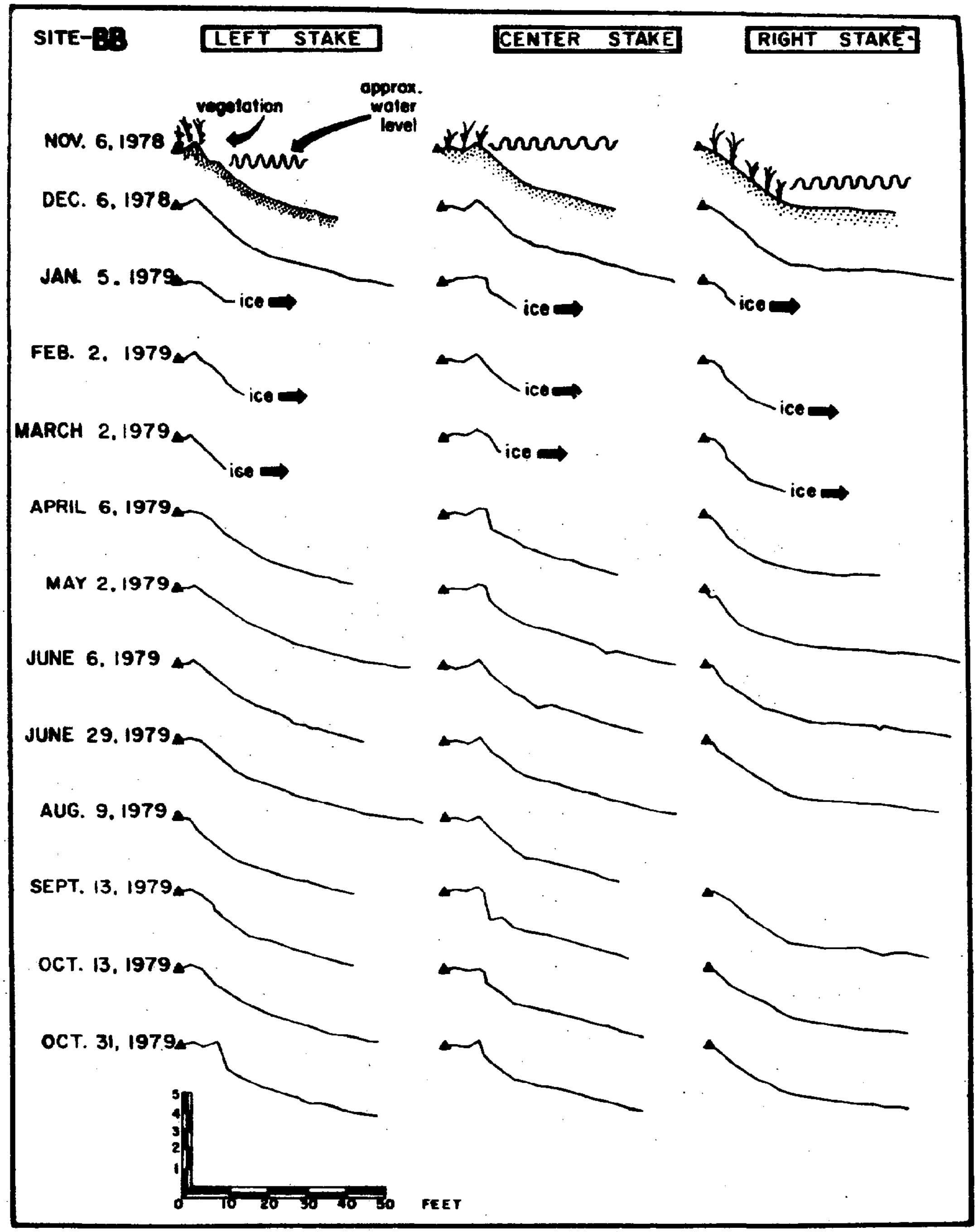


Figure 5.7



SITE-BB
LEFT STAKE
CENTER STAKE
RIGHT STAKE
vegetation
approx. water level
NOV. 6, 1978
DEC. 6, 1978
JAN. 5, 1979
ice
FEB. 2, 1979
MARCH 2, 1979
APRIL 6, 1979
MAY 2, 1979
JUNE 6, 1979
JUNE 29, 1979
AUG. 9, 1979
SEPT. 13, 1979
OCT. 13, 1979
OCT. 31, 1979
0 10 20 30 40 50 FEET
1 2 3 4 5

Figure 5.8

Creek. Immediately upstream is the bluff which is the location of the consultants' Site B discussed in the previous chapter.

The profile layout for site BB consisted of 3 transects spaced 30 feet apart along the entire section of the marsh. The vegetation at site BB consists of marsh grasses Phragmites communis and Scirpus olneyi, which extend from the water line landward to a zone of shrubs and small trees. Further landward, the marsh meets a ravine and the adjacent bluff which are full of mature trees, shrubs, vines and considerable undergrowth.

Sediment samples at site BB were collected from the beach, marsh, and nearshore zones within the upper 1-2 inches of the shoreline profiles. The sediments collected near the profile origins were composed of sand with a relatively minor silt and clay content (Table 5.1). The sample collected for analysis also contained well-sorted gravel. At the site, the relatively firm sand along the foreshore blends into finer-grained, less consolidated sediment offshore (Table 5.1). These nearshore sediments are considered to be derived partly from the erosion of the adjacent bluff and partly from finer-grained sediment carried into South River from Flat Creek.

The mean tidal range in the area of site BB is approximatley 1.0 foot, and there were no shoreline structures present along the reach that were considered to

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Opposite: Figure 5.8 Comparison of monthly profiles collected at Site BB.

interfere with sediment transport at the site during the year of study.

The shoreline of the marsh receives boat-wake energy from boats travelling on the South River generally at distances greater than 1000 feet. More localized boat traffic is generated from boats which circle Goose Island, and pass within 100-200 feet of the study site. A large percentage of these boats are towing waterskiers and tend to make multiple passages of the shoreline in a relatively short period of time. Boating traffic for the shoreline reach where sites B and BB are located is discussed further in chapters VI and VII.

The marsh also receives wind waves which approach with the longest fetches from the north-northwest. Regional winds from this direction can generate appreciable wave energy which would focus on site BB, but these winds also tend to drive water out of the rivers on the western shore so the erosive power of the waves is expended at lower levels on the beach and in the nearshore, rather than on the fastland boundary of the marsh.

Monthly profiles collected at site BB are illustrated in Figure 5.8. The fastland boundary for site BB was defined as the edge of vegetation, and showed little or no retreat for all 3 profile stakes during the year of study. Comparative profiles in Figure 5.8 do clearly show modulation of beach face sediments, but the fastland boundary for all 3 stakes remained relatively unchanged.

One major instance of visible fastland retreat at site BB occurred after the passage of Tropical Storm David September 8-9, 1979. Figure 5.8 shows the beach profile at the center stake experienced a slight fastland loss and a substantial loss of nearshore sediments between the profile dates of August 9, 1979 and September 13, 1979 after the passage of David. These nearshore sediments were presumably lost during the storm and were partially replaced by erosion from the adjacent bluff within one month. In summary, some modulation of nearshore sediments occurred at all three stakes, but no notable fastland changes can be attributed to boating. The only notable fastland change at this site can be attributed to the passage of Tropical Storm David.

Site CC: A bluff in Broad Creek off the upper South River.

This site is located approximately 1200 feet north of the mouth of Broad Creek (Figure 5.9). The shoreline segment chosen for monitoring is located at the base of a bluff which has a maximum elevation of 60 feet. The profiles at this site are located approximately 50 feet downstream from the marshy promontory which is the location of the consultants' Site C discussed the previous chapter.

Next pages: Figure 5.9 (left) Location map showing Site CC.

Figure 5.10 (upper right) Aerial view of Site CC.

Figure 5.11 (lower right) Typical profile of Site CC in October 1978.

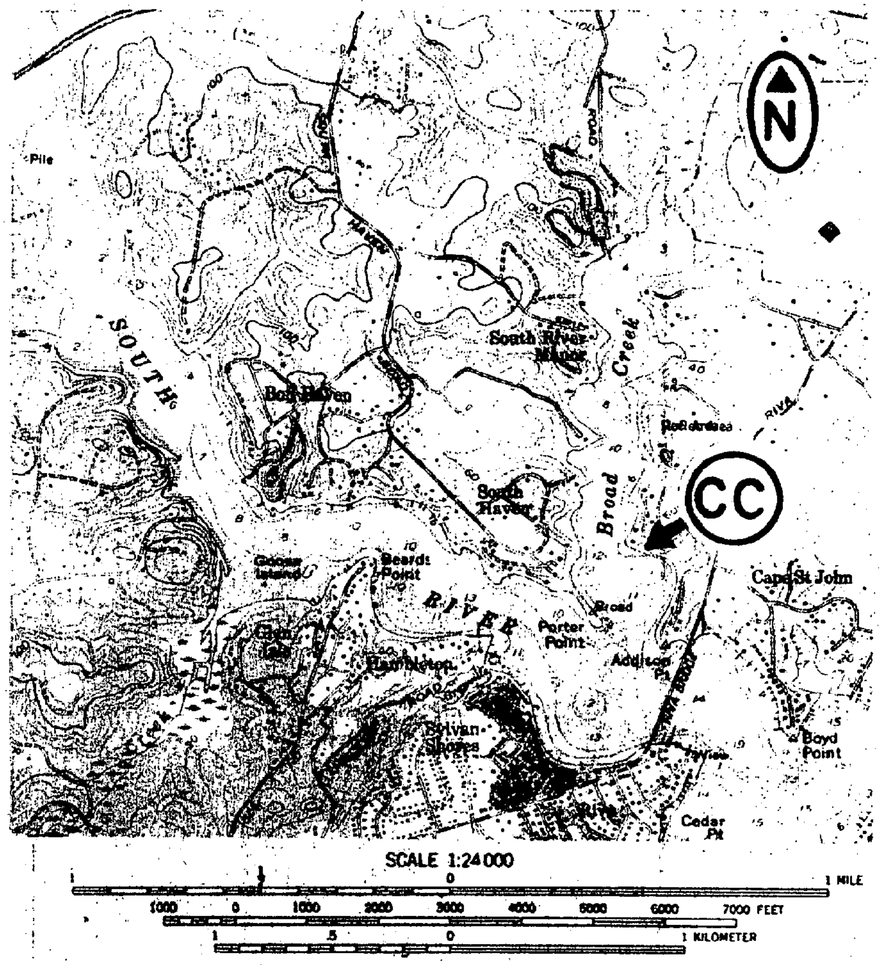
N
CC
Pile
SOUTH
RIVER
South River Manor
Broad
Creek
South Haven
Goose Island
Beards Point
Cape St John
Porter Point
Broad
Addison Pt
Hamilton
Sylvan Shores
Boyd Point
Cedar Pt
SCALE 1:24 000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

Figure 5.9

Figure 5.10

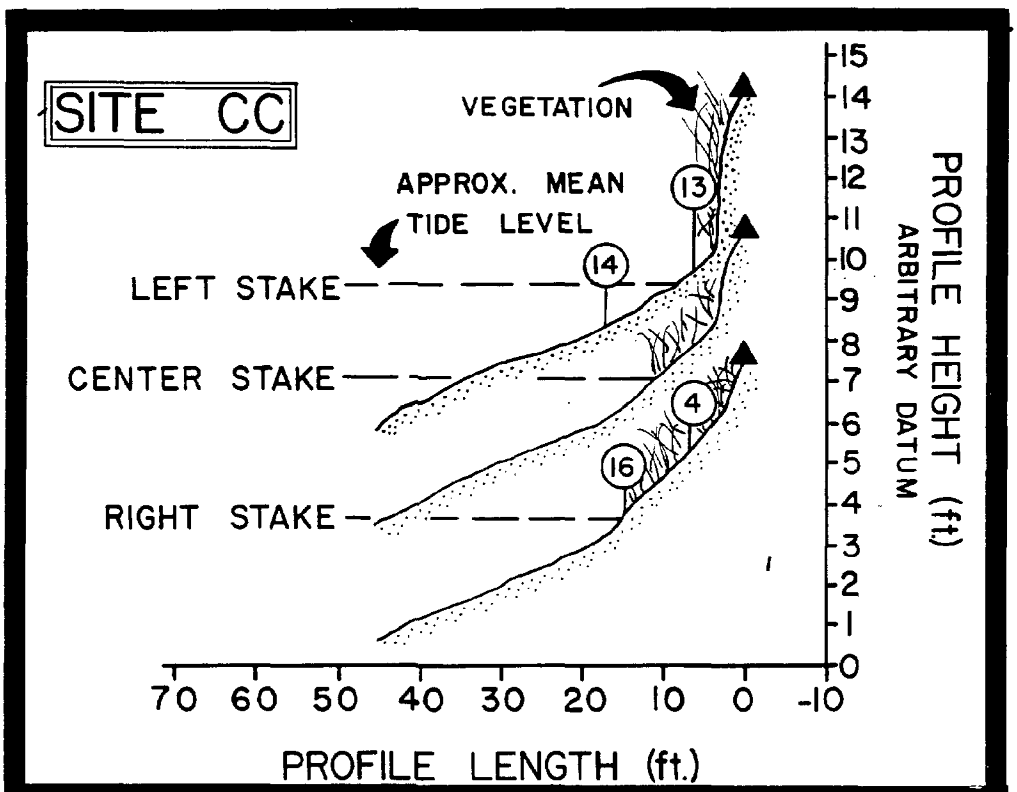

Figure 5.11

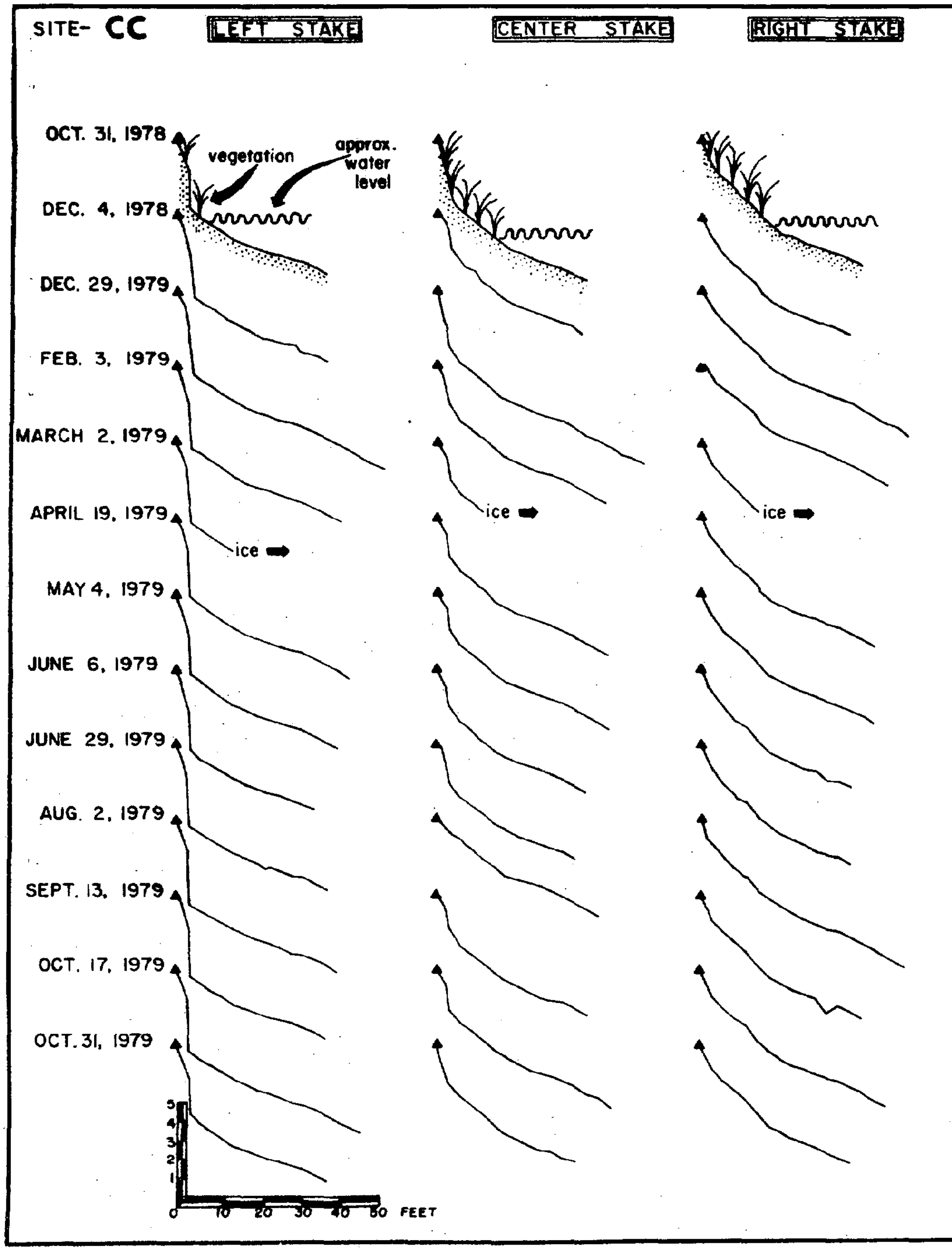
SITE- CC
LEFT STAKE
CENTER STAKE
RIGHT STAKE
OCT. 31, 1978
DEC. 4, 1978
DEC. 29, 1979
FEB. 3, 1979
MARCH 2, 1979
APRIL 19, 1979
MAY 4, 1979
JUNE 6, 1979
JUNE 29, 1979
AUG. 2, 1979
SEPT. 13, 1979
OCT. 17, 1979
OCT. 31, 1979
vegetation
approx. water level
ice
FEET

Figure 5.12

The profile layout for Site CC consists of 3 transects spaced 30 feet apart. The right profile is situated at the base of a bluff that meets the beach with an approximate 30 degree sloping face. The center profile is located 30 feet further upstream along the bluff and gradually steepens to a 50 degree sloping face. The bluff continues to steepen until it reaches a nearly - vertical section located at the left profile site.

The bluff face does not contain many areas of exposed sediments and its vegetation is composed of many trees, shrubs, thick vines, and small undergrowth. The beach grasses which grow at the base of the bluff along the shoreline consist of Scirpus olneyi and clump growths of Phragmites communis. In some areas of the shoreline between the center and right profiles, the grasses are isolated clumps tightly bound at the roots. Sediments in the nearshore contain submerged clumps of dead root material. The entire shoreline contains a 2-4 foot wide section of small grass growth that begins beyond the visible swash line.

Sediment samples at Site CC were collected from the bank, beach, and nearshore zones within the upper 1-2 inches of the shoreline profiles (Table 5.1). The sediments collected from the beach and nearshore zones are considered to be principally derived from the erosion of materials within the bluff. This bluff contains predominantly sand

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Opposite: Figure 5.12 Comparison of monthly profiles collected at Site CC.

and some well-sorted gravel between 20-50 mm. Sandy sediments comprise the beach within 3-5 feet of the base of the bluff. The strands of grass on the beach at the base of the bluff must play an important role in trapping these sandy sediments. This nearshore zone also contains well-sorted gravel which appears similar in character to the gravel collected from the bluff.

The mean tidal range at this site is approximately 1 foot, and there were no shoreline structures present along the reach which interferred with sediment movement during the period of study. There is a pier adjacent to the profiles, but this pier is not considered to have an effect on shore erosion.

The shoreface of the bluff at the study site receives boat-wake energy from boats entering and exiting Broad Creek, as well as from boats travelling up and down the South River. Boats entering and exiting Broad Creek pass at distances betweeen 400-500 feet, as compared to distances greater than 1500 feet on the South River. The inventory of boating activity collected at nearby Site C shows that 63% of the boat passages were waterskiers that were making multiple passes near that shoreline in a relatively short period of time. This site also experienced considerably more boating traffic on weekends as compared to weekdays.

The shoreface of this site, being situated some 500 feet from the main channel of the Creek, receives much lower levels of boat-wake energy than the adjacent promontory marsh. The pier adjacent to Site CC extends out 130 feet and discourages most boats from making passes anywhere near the shoreface of the site. Even though the boating frequencies in this portion of Broad Creek are considered to be high, the boat-wake energy expended on the beach at site CC is relatively small.

The shoreface of Site CC also receives wind waves with the longest fetches between the south and southwest. Porter and Adison Points at the mouth of Broad Creek protect Site CC from many of the regional winds, except those focused directly into the creek. The wind roses illustrated in Appendix B show the bluff and marsh block any wind-waves when regional winds blow from the northern fetch areas, and the total wave energy expended on the beach at Site CC is negligible. Therefore the total wind-wave energy created at Site CC can be considered to be small.

The fastland boundary for Site CC was defined as the edge of vegetation for the right and center profiles. This vegetation line is also accompanied by a slight scarp which is composed of grass clumps tightly bound to the beach by root masses. The fastland boundary for the left profile was defined as either the in-place sediments forming the bluff, or the material which slumped from the bluff face.

Monthly profiles were collected at Site CC and a comparison between successive months is illustrated in Figure 5.12. Profile comparisons of successive months indicate that only very minor changes occurred at all three profile locations. The small vertical bluff face at the left profile has a web of thick tree roots which has held the sediments tightly in place. The monthly profiles at the right and center stakes show some modulation of sediments on the beach and foreshore, but neither set shows any considerable fastland retreat. There was also a small slump between the inital profile in October 1978 and the next profile in December 1978. The profile on December 29, 1978 shows removal of much of the slumped sediment from the profile at the center stake, but the subsequent profiles do not show any additional change.

In summary, only minor changes were observed at all three profile locations during the period of the study. This site is sheltered from some of the strongest winds which blow from the north-northwest. The site is located in a popular boating area, but it is protected from close passages by boats due to a pier which extends out from the shore.

<u>Site EE</u>: <u>A small bank and beach in Maynedier Creek off the upper Severn River</u>.

This site is located inside the mouth of Maynedier Creek, off the upper Severn River (Figure 5.13). The beach segment chosen for monitoring consists of a small bank and beach which is adjacent to the ravine pocket marsh at the consultants' Site E described in Chapter IV.

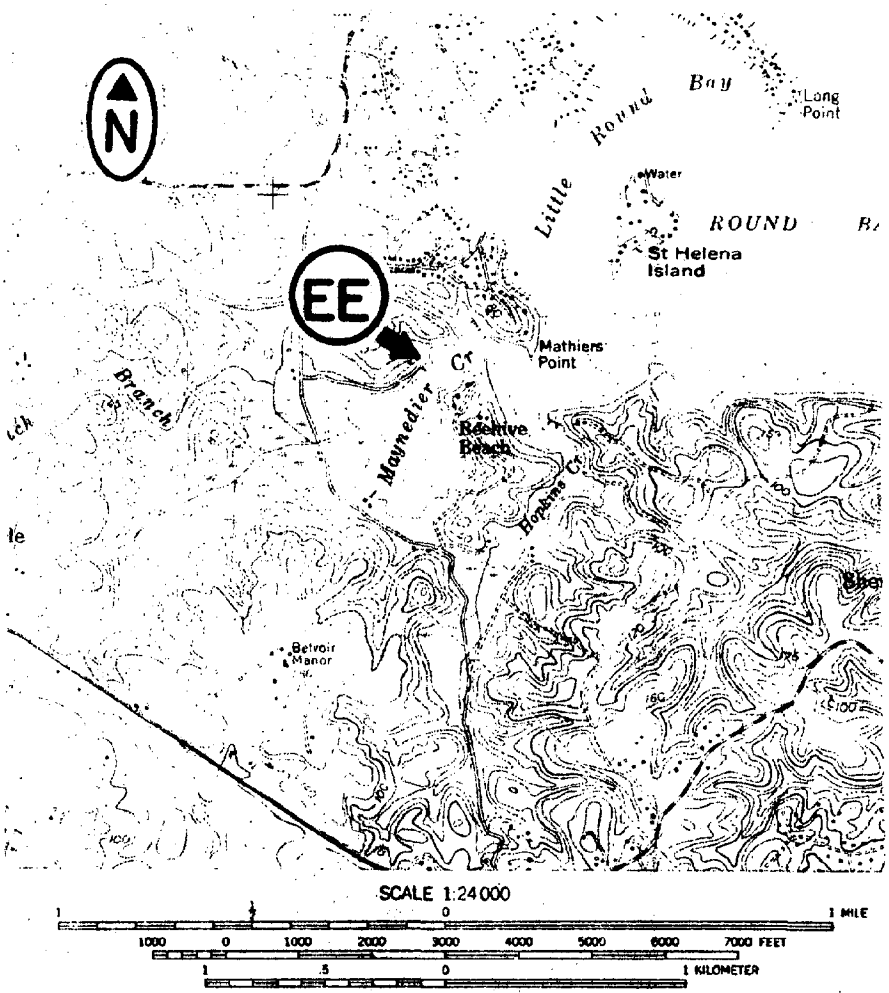
The profile layout for site EE consists of two transects spaced 30' apart. The left profile contains a small vegetated beach which is 10 feet upstream from the edge of the marsh. Landward of the beach on the left profile is a heavily-vegetated region of mature trees, shrubs, vines, and much small undergrowth. The right profile contains a beach with considerable growth of beach grasses extending 6 feet seaward of the bank. Landward of the beach on the right profile is a steep vegetated bank. The vegetation at the top of the bank consists of mature trees, shrubs, and vines.

Sediment samples at Site EE were collected from the upper 1-2 inches on the shoreline profile (Table 5.1). The sediments collected on the beach and in the nearshore are principally sand and are presumed to be derived from the erosion of the bank. The sediments in the bank contain 70% sand and some pebbles 1-3 mm. in size. The beach face in front of the bank contains 98% sand. Sediments collected from the nearshore zone approximately 4 feet seaward of the grass on the profile contained higher silt and clay content. The sandy nature of the sediments at Site EE stand in sharp contrast to the mucky consistency and high organic content of the adjacent marsh which is the consultants' Site E (Chapter IV).

Next pages: Figure 5.13 (left) Location map showing Site EE.

Figure 5.14 (upper right) Aerial view of Site EE.

Figure 5.15 (lower right) Typical profile of Site EE in October 1978.



N
EE
Bay
Long Point
Round
Little
Water
ROUND
St Helena Island
Mathiers Point
Branch
Maynedier
Beehive Beach
Hopkins Cr
Belvoir Manor
SCALE 1:24 000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

Figure 5.13

Figure 5.14

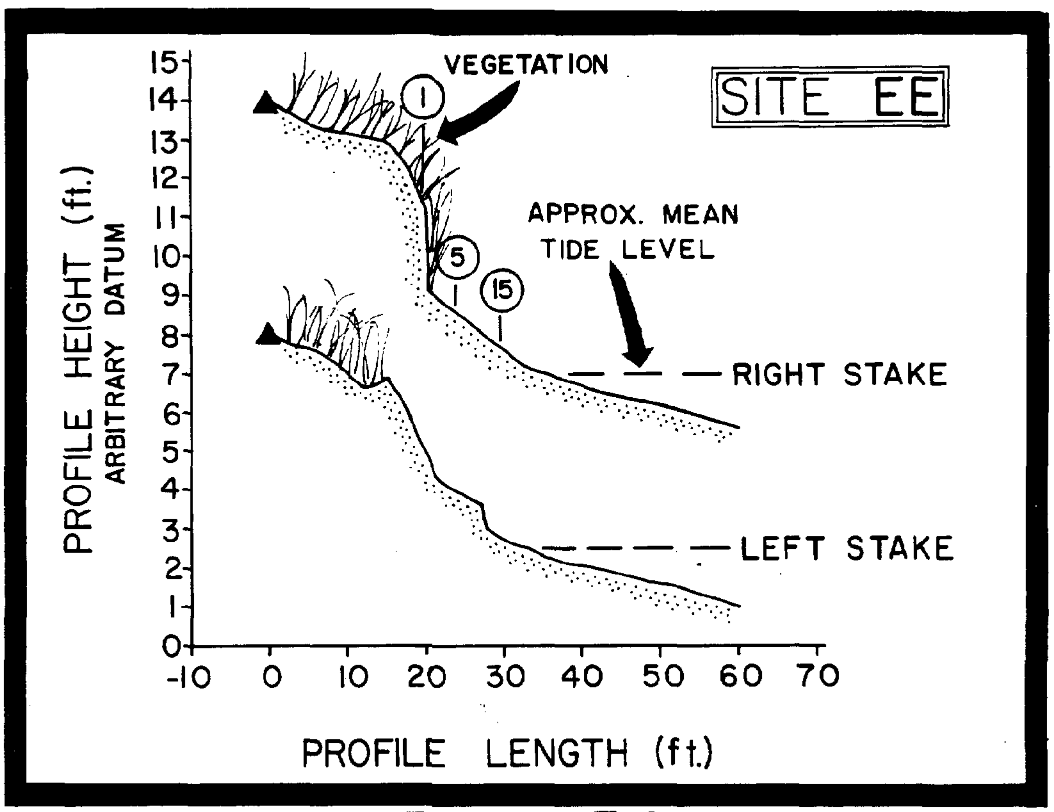


Figure 5.15

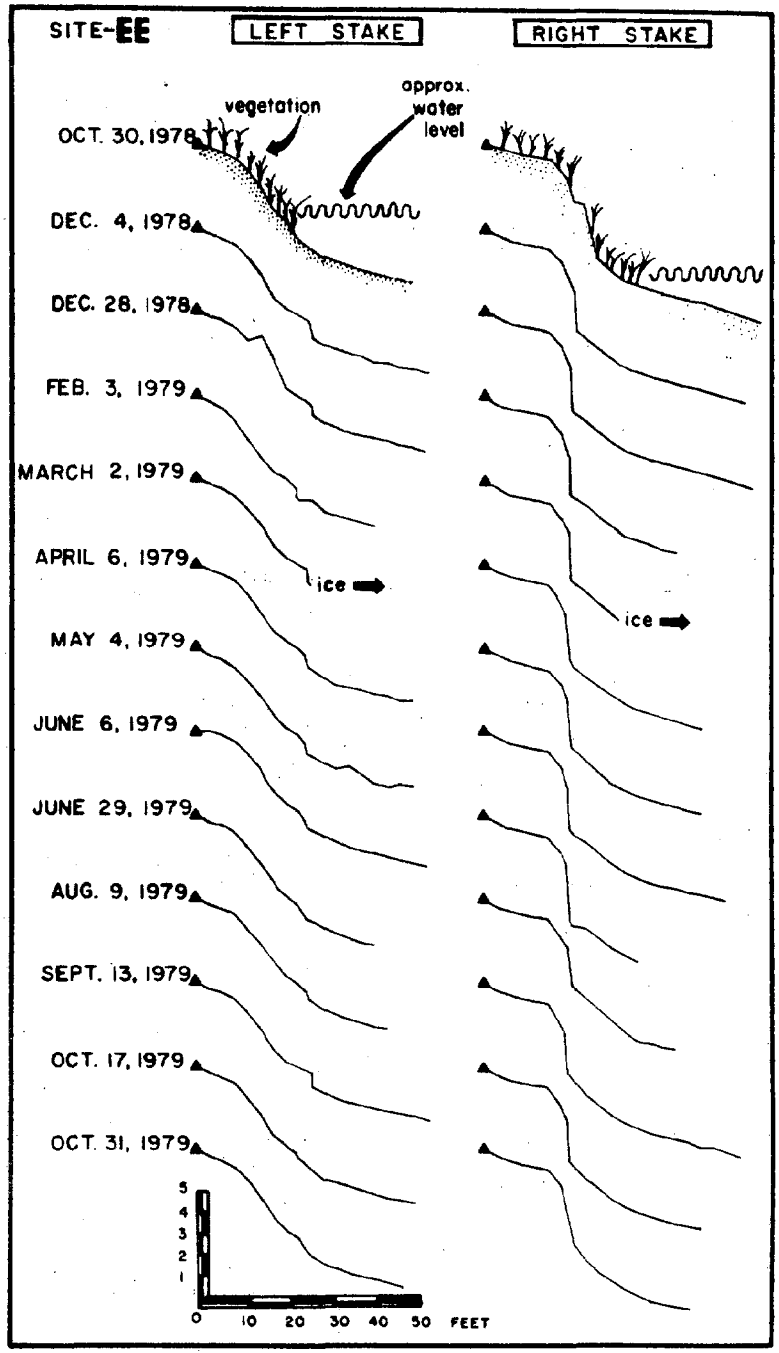

SITE-EE
LEFT STAKE
RIGHT STAKE
vegetation
approx. water level
OCT. 30, 1978
DEC. 4, 1978
DEC. 28, 1978
FEB. 3, 1979
MARCH 2, 1979
APRIL 6, 1979
ice
ice
MAY 4, 1979
JUNE 6, 1979
JUNE 29, 1979
AUG. 9, 1979
SEPT. 13, 1979
OCT. 17, 1979
OCT. 31, 1979
5
4
3
2
1
0
10
20
30
40
50
FEET

Figure 5.16

The mean tidal range at study site EE is approximately 0.8 feet. There were no shoreline protection structures present along this reach during the period of study which are considered to interfere with sediment deposition. There is a pier adjacent to the profiles, but this pier is not considered to have an effect on shore erosion.

The shoreface at Site EE receives boat-wake energy from boats entering or exiting Maynedier Creek. The boating characteristics are discussed for the consultants' Site E in Chapter VI. This study site, because of its extreme northwest location on the upper Severn River, experienced the least amount of boat-wake energy of the study sites. During the weekdays, 53% of the boats were towing waterskiers and made multiple passages of the shoreline. Maynedier Creek has a speed limit on weekends and holidays and 97% of all boats travelled at speeds of 10 mph or less.

The shoreface at Site EE also receives wind-wave energy which is fairly limited by Mathiers Point at the mouth of Maynedier Creek and by the shallow bathymetry of Round Bay beyond. The limited fetch within Maynedier Creek precludes the generation of any appreciable wind waves in the area, except at very high wind speeds. The wind-wave climate in this area is discussed in Chapter VII.

Profiles at Site EE were collected monthly and a comparison between successive months is illustrated in Figure 5.16. The fastland boundary at Site EE for the left

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Opposite: Figure 5.16 Comparison of monthly profiles collected at Site EE.

profile is defined as the landward edge of beach vegetation. The fastland boundary for the right profile site is defined as the base of the bank.

The profile comparisons indicate that only minor changes occurred at both the right and left stakes. Some of these irregularities on successive monthly profiles are due to the driftwood, falling trees, and logs which collected on the shoreline and which were not removed when the surveys were collected. For instance a comparison between the December 4, 1978 and December 28, 1978 profiles at the left stake shows some distortion caused by logs. During the boating season, the left profile experienced a slight episode of bank erosion that is evident on the August 9, 1979 profile. The next monthly profile at the left stake was collected after the passage of Tropical Storm David and more change was observed. By October 31, 1979, the sediments which had accumulated at the base of the bank were mostly removed.

In summary, there were only minor changes in the shoreline profiles at this site. A small amount of bank erosion was measured during the boating seaon, and some additional erosion was observed after the passage of Tropical Storm David.

Site FF: A beach and sandy marsh on Beards Point in the upper South River.

This site is the community beach in a subdivision known as Glen Isle (Figure 5.17). The shoreline segment chosen for monitoring consists partially of a lawn bank landward of a beach, and an adjacent marsh on Beards Point. The profile layout for Site FF contains three transects spaced 30 feet apart. Figure 5.16 illustrates the exact location of these profiles.

The vegetation for Site FF at the right and center profile locations consists of ordinary lawn grass which is maintained by cutting. This lawn grass extends up to a 2 foot scarp at the waters' edge. Beyond the scarp is a beach composed of brown sand. At the left profile stake, the vegetation consists of a dense cattail marsh which extends up to the shoreline scarp. Sediments exposed in the scarp contain very compact root masses.

Sediment samples were collected from the scarp, beach, and nearshore in the upper 1-2 inches of the shoreline profiles (Table 5.1). The sediments in the nearshore zone at Site FF are considered to be primarily derived from the erosion of the grassy beach. This is shown from samples collected from this scarp which were composed of 97% sand containing pebbles 1-10 mm. in size. The beach samples collected in front of the scarp, and the nearshore samples

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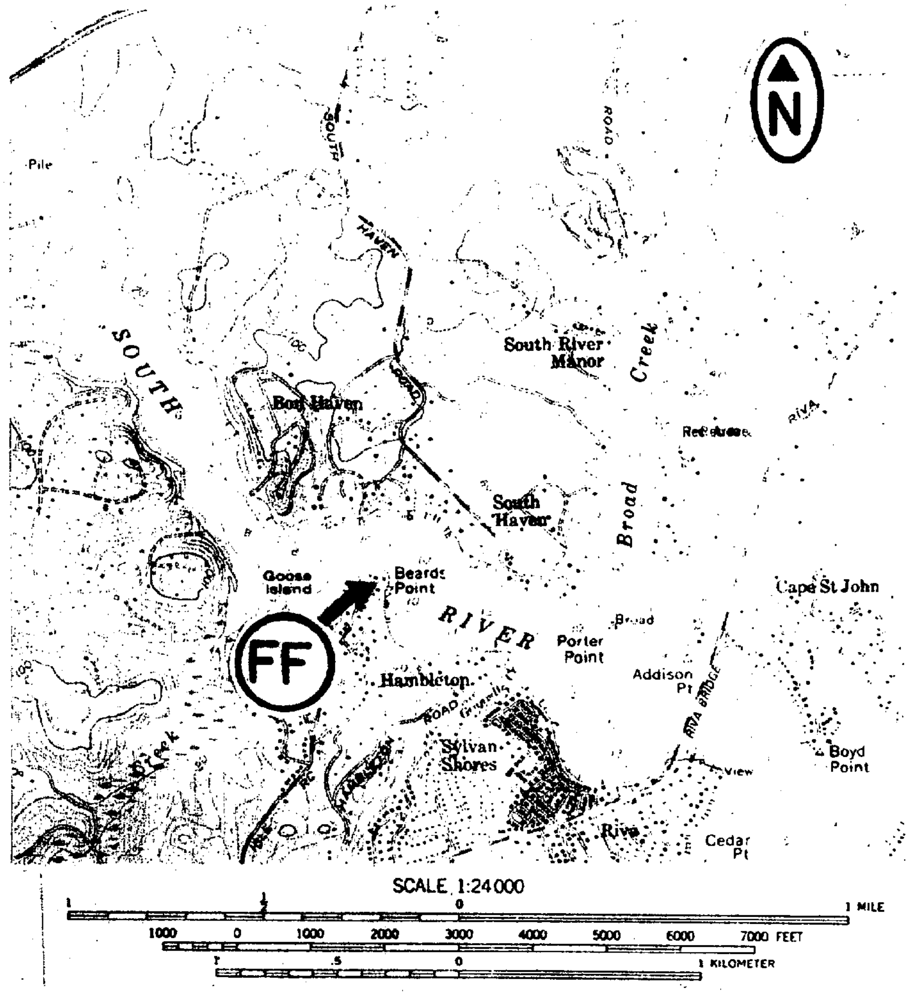
Next pages: Figure 5.17 (left) Location map showing Site FF.

Figure 5.18 (upper right) Aerial view of Site FF.

Figure 5.19 (lower right) Typical profile of Site FF in October 1978.



Pile
SOUTH
SOUTH HAVEN
ROAD
South River Manor
Creek
Broad
South Haven
Goose Island
Beards Point
FF
RIVER
Porter Point
Addison Pt
Cape St John
Hambleton
Sylvan Shores
RIVA BRIDGE
Boyd Point
Cedar Pt
N
SCALE 1:24000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER

Figure 5.17

Figure 5.18

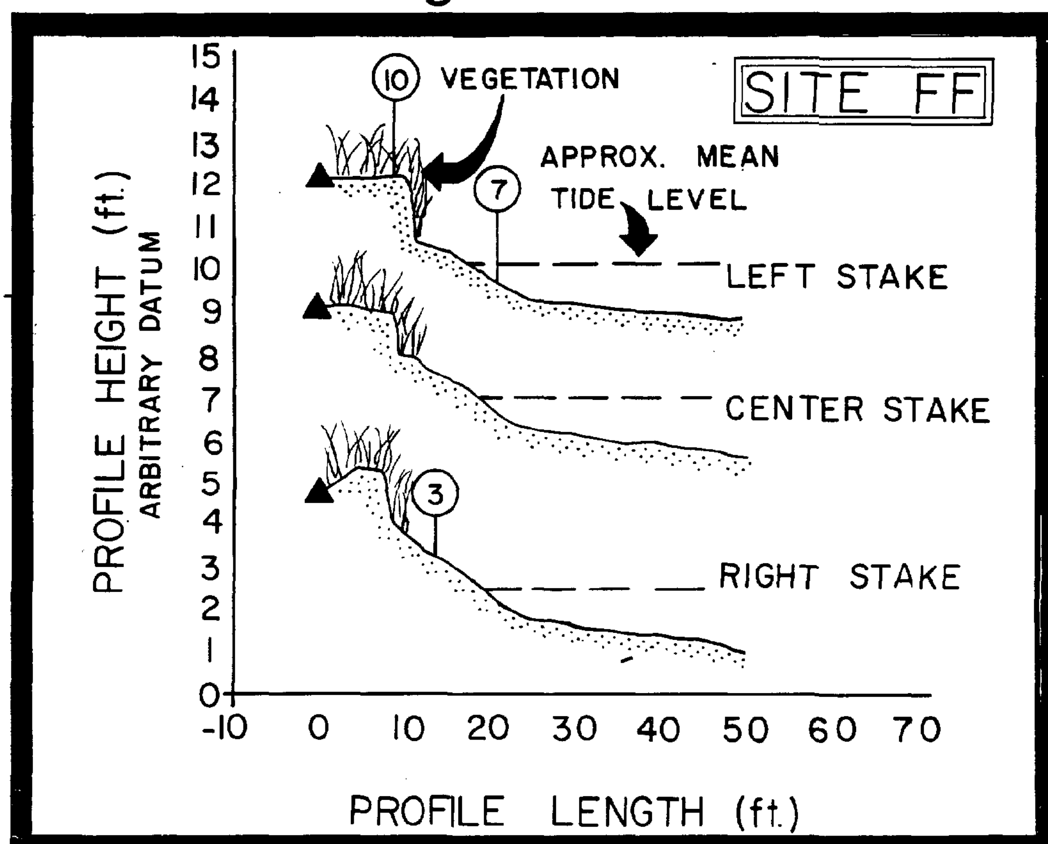


Figure 5.19

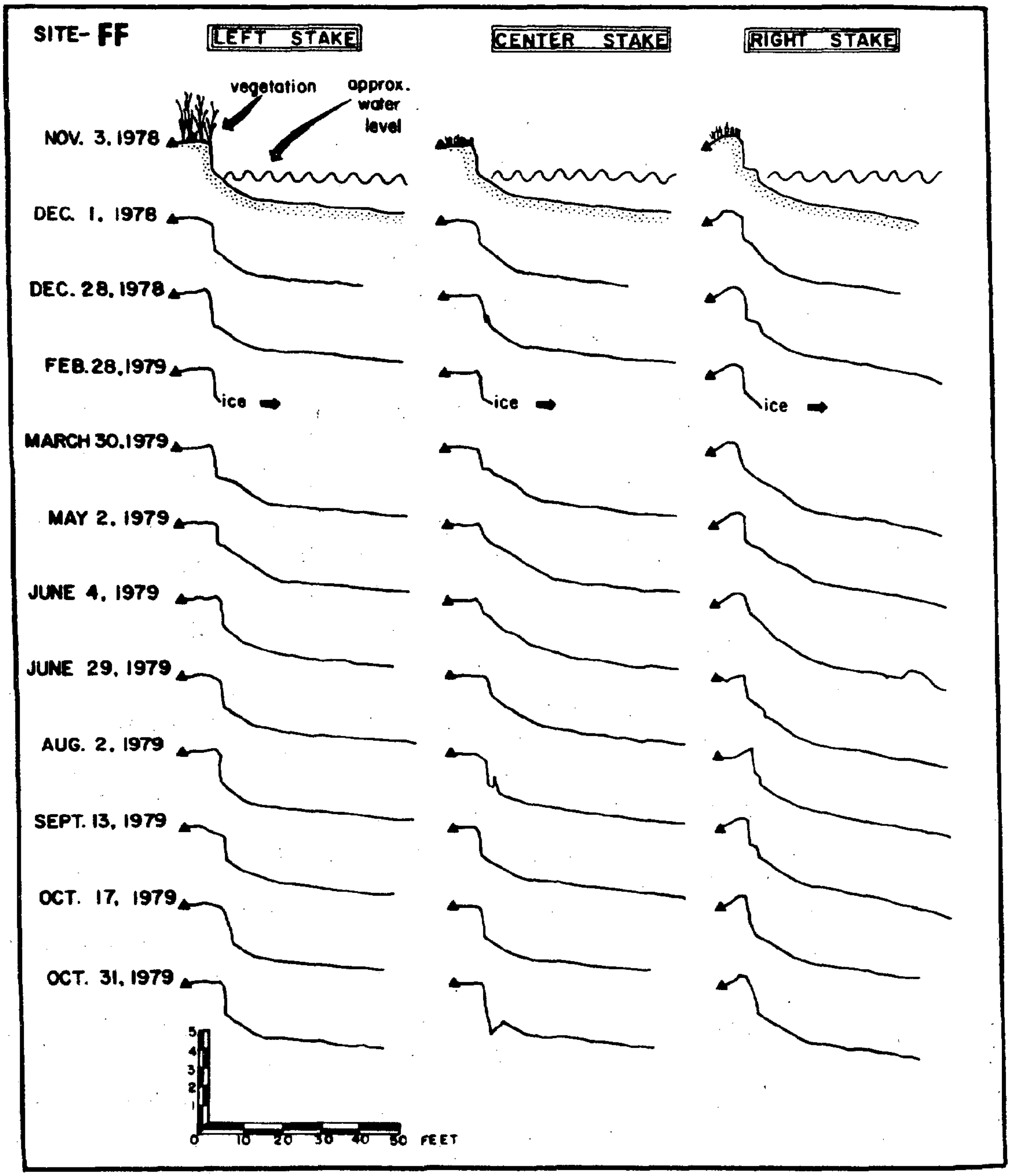

SITE- FF
LEFT STAKE
CENTER STAKE
RIGHT STAKE
vegetation
approx. water level
NOV. 3, 1978
DEC. 1, 1978
DEC. 28, 1978
FEB. 28, 1979
ice
ice
ice
MARCH 30, 1979
MAY 2, 1979
JUNE 4, 1979
JUNE 29, 1979
AUG. 2, 1979
SEPT. 13, 1979
OCT. 17, 1979
OCT. 31, 1979
5
4
3
2
1
0
10
20
30
40
50
FEET

Figure 5.20

contained 97% sand and pebbles ranging from 1-5 mm. in size. Sediment samples taken from the scarp on the left profile contained less sand and slightly more silt and clay, (Table 5.1).

The mean tidal range at Site FF is approximately 1.0 foot. The only shoreline structure present in the area is a community boat pier and mooring area which includes a wooden bulkhead that extends 10 feet out and is approximately 150 feet downstream from the study site. This pier is not considered to have an effect on shore erosion at the study site.

The shoreface of Site FF receives boat-wake energy from boats travelling up and down the South River. There is no speed limit restriction and most of the traffic is travelling at high speeds. The location of Beards Point results in relatively close passages of boats within 75-100 feet of the shoreline. Wakes from boats travelling upstream probably impact the downstream side of Beards Point in the vicinity of site FF more than wakes travelling downstream. Wakes were not measured at this site, but waves were observed to be undergoing refraction around Beards Point during the time profiles were taken.

The shoreface at Site FF also receives wind-wave energy with the longest fetches from the east and southeast. Regional winds from these directions can generate

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Opposite: Figure 5.20 Comparison of monthly profiles collected at Site FF.

appreciable wave energy which would focus directly on Beards Point. Wind waves from the northwest will create the same type of refraction previously mentioned, and could have some effect on this site.

The fastland boundary for all 3 profiles was defined as the edge of vegetation which is also the first pronounced change of slope.

Profiles at Site FF were collected monthly and a comparison between successive months is illustrated in Figure 5.20. The comparison shows that the small scarp at all three profile stakes experienced slight changes during the year of study. The left profile stake in the cattail marsh experienced the greatest change during the passage of Tropical Storm David on September 8-9, 1979. The profile for September 13 at this stake shows a change in the profile near the scarp, and erosion of sediments, when compared to the August 2 profile. There was also noticeable modulation of the sediments on the beach from month to month before the start of the boating season. But the changes in the location of the fastland boundary were minor at all of the stakes at this site.

VI

BOATING FREQUENCIES AND CHARACTERISTICS

Robert J. Byrne, John D. Boon III
Rhonda Waller, and Deborah Blades

A. Introduction

This chapter describes the frequencies of boat passes and other boating characteristics which were observed in front of those sites described in Chapter IV. At the beginning of the study, these sites were known to be located in areas of Anne Arundel County which were popular for boating, but there was no information available on the exact levels or patterns of boating which might be expected at each site. Since this information is useful in interpreting the behavior of the shoreline profiles during the boating season and at other times of the year, each of the five sites was occupied on a daily rotating basis for several weeks during the summer of 1979 (Table 6.1), to inventory the boating characteristics and to measure the boat-wake energies which are discussed in the next chapter.

The results presented in this chapter show there were markedly different frequencies of boat passes at each of the five study sites, together with different patterns of boat speeds, hull configurations, and distances of boat passes from the shoreline. The experiments with controlled boat passes discussed in Chapter VIII show specifically how these different characteristics can affect the wave heights (and

Next pages: Table 6.1 Boating inventories at the study sites.

<u>Table 6.1 Dates and Sites of Boating Inventory</u>

Date	Day	Site	Total Boats	Average Boats/Hr.	Weather
25 May	Fri	A	98	14	
26	Sat	B	72	9	
27	Sun	C	208	26	
28	Mon	D	522 Navy Day	75	
29	Tue	E	1	0	Rain
30	Wed	A	221	28	
31	Thr	C	5	1	Rain/Haze
1 June	Fri	B	18	3	
2	Sat	D	231	29	Rain
3	Sun	E	9	4	Rain
4	Mon	A	64	13	
5	Tue	B	206	26	
6	Wed	C	107	13	
1 July	Sun	A	400	100	
2	Mon	B	67	10	
3	Tue	C	203	25	
4	Wed	D	281	70	
5	Thr	E	35	5	
6	Fri	A	357	45	
7	Sat	B	511	64	
8	Sun	C	647	81	
9	Mon	D	174	22	
10	Tue	E	39	6	
11	Wed	A	188	24	
12	Thr	B	149	19	
13	Fri	C	88	15	Haze/Rain
14	Sat	D	397	50	
15	Sun	E	120	15	
16	Mon	A	234	29	
17	Tue	B	106	13	
18	Wed	C	149	19	
19	Thr	D	148	18	
20	Fri	E	62	12	Haze/Rain
21	Sat	A	302	76	
22	Sun	B	537	67	
23	Mon	C	90	13	Haze/Rain
24	Tue	D	118	15	Rain/Clear
25	Wed	E	38	6	
26	Thr	A	170	21	Haze/Rain
27	Fri	B	104	15	
28	Sat	C	337	42	
29	Sun	D	438	63	
30	Mon	E	30	4	
31	Tue	A	171	21	

Date	Day	Site	Total Boats	Average Boats/Hr.	Weather
1 Aug	Wed	B	159	23	
2	Thr	C	118	20	
3	Fri	D	105	21	
4	Sat	E	106	13	
5	Sun	A	1505	188	
6	Mon	B	107	13	
7	Tue	C	147	18	
8	Wed	D	127	16	
9	Thr	E	74	12	
10	Fri	A	187	23	
11	Sat	B	257	51	Haze/Rain
12	Sun		No Data		
13	Mon		No Data		
14	Tue	E	46	6	
15	Wed		No Data		
16	Thr	B	30	6	
17	Fri	C	75	9	
18	Sat	D	228	28	Clear/Rain
19	Sun	E	84	10	
20	Mon	E	49	6	
21	Tue		No Data		
22	Wed	C	85	11	
23	Thr	D	86	11	
24	Fri		No Data		
25	Sat		No Data		
26	Sun	B	215	43	
27	Mon	C	43	6	
28	Tue	D	44	6	
29	Wed		No Data		
30	Thr	E	28	7	
31	Fri	B	26	4	
1 Sept	Sat	C	113	28	
2	Sun		No Data		
3	Mon	B	60	8	
4	Tue	A	15	2	
5	Wed		No Data		
6	Thr		No Data		
7	Fri	B	11		
8	Sat	E	30	4	
9	Sun	D	38	5	
10	Mon	B	28	4	
11	Tue	C	32	5	
12	Wed	D	40	7	
13	Thr	E	0	0	
14	Fri		No Data		
15	Sat		No Data		

transect	month	day	year	time E.S.T.	wind dir.	speed (L)	speed (H)	qualifier	clouds	visibility	position: still water	breakers	swash (L)	swash (S)

wind qualifier
S - steady
G - gusts
C - calm
V - variable

cloud cover
0 - clear
1 - scattered
2 - broken
3 - overcast

visibility
H - haze
R - rain
F - fog
U - unlimited

time	boat	boat speed (mph)	hull length (feet)	type	skier?	sailing?	direction	distance (feet x 10)
____	1	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	2	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	3	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	4	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	5	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	6	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	7	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	8	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	9	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	10	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	11	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	12	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	13	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	14	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	15	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	16	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	17	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	18	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	19	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	20	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	21	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	22	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48
____	23	5 10 15 20 25 30	12 14 16 18 22 26 30	P D S	Y	Y	US DS UT	6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48

Figure 6.1

thus the wave energy) in wakes which break along the shoreline. The experimental data helps to explain why there is not a clear increase in boat-wake energy (discussed in the next chapter) at the sites with the highest boating frequencies.

B. Methods

An inventory of boating activity was conducted at the study sites during an initial 13 day period (25 May - 6 June, 1979) and a following 77 day period (1 July - 15 September, 1979). The initial sampling design called for each site to be inventoried on each day of the week twice (i.e. 2 Sundays, 2 Mondays, etc.). This level of sampling strategy was determined by the fiscal constraints on the study; these constraints precluded anything other than a simple rotation of a single observer from site to site in a sequential series.

An observer categorized all boats passing at each site between 1000 hrs. and 1800 hrs. EDST. Figure 6.1 shows an example of the log sheet which was used on each day that observations were made. Each boat passing the study site was logged, in sequence, noting:

- o Time of day.
- o Boat speed (estimated).
- o Hull length (estimated).
- o Hull type; displacement or planning.
- o Sail boat.

Opposite: Figure 6.1 The log sheet which was used to inventory boating frequencies and other characteristics at the profile sites described in Chapter IV.

- o Presence of a skier in tow.
- o Direction: upstream, downstream or turning.
- o Distance: estimated or determined with range finder.

On each of the days when boats were inventoried at a site, the incoming boat-wake waves were also measured using a surface electronic wave gauge with a strip-chart recorder output (described in Appendix C). The wave heights were used to construct the wake-energy budgets, which are described for each study site in Chapter VII.

When boating activity and boat wakes were measured at a certain study site, observations were also made each hour of:

- o Wind speed and direction at the study site, using a wind-speed gauge and compass.
- o Cloud cover noted as clear, scattered, broken, or overcast.
- o Visibility: haze, rain, fog, unlimited.
- o Position of still water on the shoreline profile.
- o Position of the breaker zone and the upper and lower limits of the swash zone on the shoreline profile.
- o Hourly recording of the wind-wave field using the wave gauge.

C. Results

A comparison of the boating statistics for all the sites is given in Table 6.2. Daily summaries of all the

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Opposite: Table 6.2 Comparison of the boating statistics for all of the study sites.

TABLE 6.2 Summary of Boating Characteristics and Boating Activity: Site Averages Expressed as a Percent

Site	Avg.	Boats/Day	Speed (mph)				Hull Length (ft)				Type		Skier	Sail	Distance (ft)				
			≤10	20	30	>30	≤16	22	30	>30	P	D			≤100	200	360	480	>480
A	WD	170.5	29	47	23	1	32	32	24	12	75	25	14	7	12	34	8	0	46
	WE	735.7	41	31	27	1	33	34	23	10	54	46	0	15	1	8	26	0	65
B	WD	91.9	14	60	26	0	49	35	11	5	82	18	46	0	3	12	5	4	76
	WE	344.2	9	78	12	1	45	45	9	1	91	9	45	0	3	7	4	6	80
C	WD	95.2	9	75	15	1	53	40	7	0	90	10	63	0	28	56	16	0	0
	WE	326.2	11	76	13	0	49	39	12	0	87	12	57	0	36	47	17	0	0
D	WD	155.8	22	37	35	6	27	21	28	24	73	27	2	8	0	1	2	6	91
	WE/H	268.8	30	43	26	1	26	35	25	14	68	32	1	17	0	1	1	2	96
E	WD	44.6	23	51	26	0	59	35	5	1	76	24	53	4	18	68	14	-	-
	WE	69.8	97	2	1	0	63	20	11	6	3	97	1	10	3	55	42	-	-

WD = Weekday Averages; WE/H = Weekend, Holiday Averages

WE = Weekend Averages; P = Planing; D = Displacing boating characteristics at each site are presented in Tables 6.3 thru 6.7.

SITE DESCRIPTIONS

Site A is located on the vegetated spit along the lower South River near the entrance to Harness Creek. There are two distinct patterns of boating in the vicinity of this site. One group of boats operates in a popular sailing area well away from the shoreline, out near the main channel of the lower South River. Another group of boats enters and leaves a popular anchorage area in Harness Creek, and passes the study site at a much closer distance.

Table 6.3 shows that the total frequency of boat passes, and the portion of boats passing close to shore at Site A can vary from day to day, and from weekday to weekend. The summary of data from all sites in Table 6.2 shows that, on the average, more than two-thirds of the weekend boat passes at Site A take place well away from the shoreline out in the South River and a larger percentage of the weekday boat passes at Site A take place nearer to the mouth of Harness Creek.

Opposite: Table 6.3 Daily inventory of boating activity for Site A.

Table 6.3 Inventory of Boat Activity, Daily Summaries

Site A

Date (1979)	Day	Total Boat Passes	Boat Speed (mph)				Hull Length (ft)				Type		Skier	Sail	*Distance (ft x 10)				
			≤10	20	30	>30	≤16	22	30	>30	P	D			≤10	20	36	48	>48
25 May	Fri	98	30	50	18		18	43	19	18	48	50	2	-	18	18			62
30 May	Wed	221	33	54	117	17	14	53	59	95	178	43	32	-	56	57			108
4 Jun	Mon	64	43	21			6	21	21	16	52	12		-	19	7			38
1 Jul	Sun	400	162	126	112		43	118	78	61	200	194	2	-		21	124	1	247
6 Jul	Fri	357	152	204	1		115	109	83	42	283	14	57	26	50	126	26	1	178
11 Jul	Wed	188	26	126	30	2	87	58	27	10	171	2	38	12	17	86	34		46
16 Jul	Mon	234	61	103	70		120	61	41	13	170	40	43	24	3	46	56		127
21 Jul	Sat	302	130	123	45	4	75	126	96	6	165	97	2	43	18	108	2		152
26 Jul	Thr	170	46	93	29	2	62	69	32	7	107	46	52	17	25	85	11		43
31 Jul	Tue	171	50	58	70	2	72	55	44	6	90	74	8	17	17	68	5		92
3 Aug	Sun	1,505	616	436	431	22	573	479	318	153	653	572	4	285	1	37	454	1	1,021
10 Aug	Fri	187	54	84	49	1	46	70	71	2	73	98	10	19	6	83			98
4 Sep	Tue	15	4	9	2		4	6	3	3		15				15			

7% of the weekday boat passes at Site A consisted of sailboats compared to 15% of the weekend boat passes. This observation partially explains the lower percentage of planing boats which were present in the weekend boating patterns. The average frequency of boat passes on weekends at Site A was 4 times as high as on weekdays. The average hull length and average speed were approximately the same on both weekdays and weekends.

Most important, Table 6.2 shows Site A experienced more boat passes on both weekdays and weekends, on the average, than any of the other 4 study sites whose profiles are described in Chapter IV.

Site B is located at the steep bank on the upper South River near Goose Island. This site is located along a relatively straight reach of shoreline, and in a relatively sheltered portion of the upper South River. The site is not near any popular anchorage or docking facility, and is a popular running ground for high-speed power boats and ski boats.

This popularity is reflected in several of the statistics of boat use on Tables 6.2 and 6.4. Virtually no boats under sail were observed at this site, and almost 50%

Opposite: Table 6.4 Daily inventory of boating activity at Site B.

Table 6.4 Inventory of Boat Activity, Daily Summaries

Site B

Date (1979)	Day	Total Boat Passes	Boat Speed (mph) ≤10	20	30	>30	Hull Length (ft) ≤16	22	30	>30	Type P	D	Skier	Sail	Distance (ft x 10) ≤10	20	36	48	>48
26 May	Sat	72	7	55	10		39	28	5		60	12	23	-	2	29	21	15	15
1 Jun	Fri	18	11	7			2	12	4		12	6		-	1	1	1	1	14
5 Jun	Tue	206	62	144	1		4	90	101	11	195	11	80		9	11	14	4	168
2 Jul	Mon	67	13	53	1		13	39	13	2	58	10	32						67
7 Jul	Sat	511	60	447	8		63	379	92	10	508	5	191	3	22	30	12	31	419
12 Jul	Thr	149	12	127	10		132	83	4	4	147	1	91		5	16	3	4	121
17 Jul	Tue	106	4	101	1		61	39	6		105		71		3	1	1	4	97
22 Jul	Sun	537	40	420	71	6	359	167	25	1	493	60	287	1	3	31	10	21	490
27 Jul	Fri	104	4	88	12		61	39	4		96	7	55		4	9	5	5	82
1 Aug	Wed	159	3	62	94		110	31	2	37	127	19	87		2	20	8	10	107
6 Aug	Mon	107	17	73	26	1	67	48			84	34	53		3	12	2	6	94
11 Aug	Sat	257	14	162	79	2	181	77	2		200	46	121		10	14	8	20	209
16 Aug	Thr	30	3	23	4		16	14			22	8	12			1	3	1	25
26 Aug	Sun	215	8	42	162	3	184	30	6	5	176	50	97		1	26	12	16	184
31 Aug	Fri	26	3	5	16	2	8	15	1	2	10	16	4		1	7	2	4	13
3 Sep	Mon	60	36	24			13	26	6	14		61		4	2	45	7		
7 Sep	Fri	11	2	1	8		1	9	1		8	3	5			10	1		
10 Sep	Mon	28	4	21	2		13	11	4		19	9	8		3	2	3	2	18

of the total number of boats inventoried were pulling skiers both on weekdays and weekends. About 90% of all boats inventoried had speeds which were estimated at 10 mph or more, and lengths of 22 feet or less. Between 75 and 80% of the boats remained more than 480 feet from the shore, probably because of shallow depths and obstructions (tree trunks) near the shore at Site B.

Table 6.4 shows that Site B had, on the average, the second-highest frequency of boat passes (next to Site A) on the weekends. The average number of boats on the weekends was slightly less than 4 times the average number of boats on weekdays.

Site C is located at the small promontory on Broad Creek near the entrance to the South River. Broad Creek is comparatively deep along both shores and relatively straight. Like Sites A and B, considerably more boating activity occurred on weekends as compared to weekdays. Table 6.5 shows Site C experienced the second largest boating frequency on weekdays of the five sites, and some 63% of its average 95 boats per day were pulling skiers. Table 6.2 shows about 93% of the weekday boats were 22 feet or less in length and about 90% had speeds exceeding 10 mph. More than 80% of all boats observed passed within 200 feet

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Opposite: Table 6.5 Daily inventory of boating activity at Site C

Table 6.5 Inventory of Boat Activity, Daily Summaries

Site C

Date (1979)	Day	Total Boat Passes	Boat Speed (mph)				Hull Length (ft)				Type		Skier	Sail	Distance (ft x 10)				
			≤10	20	30	>30	≤16	22	30	>30	P	D			≤10	20	36	48	>48
27 May	Sun	208	27	147	34		63	92	51	2	172	36	73	-	131	77			
30 May	Thr	5																	
6 Jun	Wed	107	29	74	2	2	30	63	14		87	20	58	-	45	56	6		
3 Jul	Tue	203	13	189	3		23	119	52		201	3	145		90	71	17		4
8 Jul	Sun	647	69	542	33	3	366	174	93	3	638	9	400		147	228	191	1	
13 Jul	Fri	88	6	75	8		69	22			91		70		5	71	22		
18 Jul	Wed	149	7	133	7	2	85	63			145	4	97		55	64	31		
23 Jul	Mon	90	7	74	4	5	64	25	1		55	34	51		20	61	6		
28 Jul	Sat	337	34	249	54		143	184	8		241	90	204		121	202	9		
2 Aug	Thr	18	6	88	23		53	65			94	24	89		25	78	5		
7 Aug	Tue	147	13	121	12		106	35	6		97	50	98		48	95	4		
17 Aug	Fri	75	6	35	34		69	4	2		63	12	47		4	35	48		
22 Aug	Wed	85	9	18	58		73	12			74	11	48		5	47	31		
27 Aug	Mon	43	3	20	18	2	15	25	2	1	33	10			10	30	6		
1 Sep	Sat	113	9	57	44	3	54	52	7		89	24	65		37	64	11		
11 Sep	Tue	32	1	23	6	2	8	18	6		22	10	15		7	27			

of the shore and roughly 30% came within 100 feet of shore. Thus Site C is clearly a site in which a high level of activity was concentrated very near the shoreline being monitored.

Site D is located at the bluff near Severnside on the northern shore of the Severn River. This site is the most exposed of the five sites to wind-wave activity. Compared to the sites discussed for the South River, weekend boating activity was not greatly in excess of that observed during weekdays, even though the Fourth of July holiday was included among the former. Table 6.2 and 6.6 shows that very little skiing was observed at this site and boating characteristics were rather mixed with a broader distribution of boat speeds and lengths than at other sites. This was not unexpected in view of the close proximity of Site D to the port of Annapolis, a major center for yachts of all types. It is also apparent in Table 6.6 that most of the boating activity occurs well out in the Severn. Most of the traffic appears to be transiting to and from the Bay.

Site E is located at the pocket marsh inside a cove that opens to the Severn River. The site is well protected,

Opposite: Table 6.6 Daily inventory of boating activity at Site D.

Table 6.6 Inventory of Boating Activity, Daily Summaries

Site D

Date (1979)	Day	Total Boat Passes	Boat Speed (mph)				Hull Length (ft)				Type		Skier	Sail	Distance (ft x 10)				
			≤10	20	30	>30	≤16	22	30	>30	P	D			≤10	20	36	48	>48
28 May	Mon	522	34	181	243	69	16	74	177	249	374	138	-	-		5			522
2 Jun	Sat	231	99	127	5		24	58	68	91	163	68	1	-		6			225
4 Jul	Wed	281	90	129	62		67	184	58	32	175	46	2	65	1	5	1	1	273
9 Jul	Mon	174	47	86	40		77	45	41	13	144	5	17	-	1				173
14 Jul	Sat	397	92	171	130	4	178	121	46	46	244	72	1	25			7	4	385
19 Jul	Thr	148	69	61	18		73	30	42	1	86	21	1	41			2	59	87
29 Jul	Sun	438	96	161	155	15	102	152	170	14	209	146	3	88	1	1	2	3	444
3 Aug	Fri	105	29	36	39	1	55	15	15	19	48	39	6	17		5	7	1	90
8 Aug	Wed	127	36	47	41		45	37	41	4	72	41	2	19		3	1	3	119
18 Aug	Sat	228	104	85	36	1	53	55	65	49	72	70	10	86			2	2	224
23 Aug	Thr	86	29	26	29	2	35	25	15	11	48	20	-	18				1	85
28 Aug	Tue	44	9	8	19	7	12	24	4	5	19	24	-	1		3	13	5	22
9 Sep	Sun	38	6	9	21	1	4	25	5	3	16	18	4	3		2	10	16	10
12 Sep	Wed	40	15	12	11	2	14	12	14		21	12	-	7				3	37

the nearshore zone is muddy and extremely shallow at low tide in the vicinity of the monitoring site. In contrast to the other sites, Site E experienced minimal boating activity during both weekday and weekend observation periods. Roughly 60% of all boats inventoried had lengths of 16 feet or less. On weekends, 97% of all boats travelled at speeds of 10 mph. or less. Skiing activity accompanied about 53% of weekday boating, but dropped to about 1% during weekends. This is an indication that the weekend skiing restriction is being respected by the boaters.

Opposite: Table 6.7 Daily inventory of boating activity at Site E.

Table 6.7 Inventory of Boating Activity, Daily Summaries

Site E

Date (1979)	Day	Total Boat Passes	Boat Speed (mph) ≤10	20	30	>30	Hull Length (ft) ≤16	22	30	>30	Type P	D	Skier	Sail	Distance (ft x 10) ≤10	20	36	48	>48
29 May	Tue	1																	
3 Jun	Sun	9	8			1	3		3	2	2	7			2	6	1		
5 Jul	Thr	35	18	17			28	6	1		26	4	6	6	3	11	22		
10 Jul	Tue	39	6	32	1		15	21	3		38	1	29	-	1	35	3		
15 Jul	Sun	120	116	3	1		82	23	8	7	4	111	4	5	5	23	91		
20 Jul	Fri	62	8	39	15		37	20			59	4	36	2	26	34	1		
25 Jul	Wed	38	7	25	6		34	1	4		29	9	28	-		34	4		
30 Jul	Mon	30	13	3	1		25	6	2		17	13	13	3	1	30	1		
4 Aug	Sat	106	104	1	1		56	28	16	7	2	65	1	21	3	85	18		
9 Aug	Thr	74	9	42	23		15	55	4		49	23	41	2	4	66	4		
14 Aug	Tue	46	11	22	13		31	13	2		33	11	29	2	1	38	7		
19 Aug	Sun	84	80	3	1		61	13	5	6	2	77		5	1	57	27		
20 Aug	Mon	49	13	10	26		42	4	2	1	30	17	26	2		33	16		
30 Aug	Thr	28	4	6	18		8	17	2	2	16	11	6	1	5	20	3		
8 Sep	Sat	30	30				16	6	8			27		3		19	9		
13 Sep	Thr	0																	

VII

COMPARISON OF BOAT-WAKE AND WIND-WAVE ENERGY BUDGETS

Robert J. Byrne, John D. Boon III,
Rhonda Waller and Deborah Blades

A. Introduction

This chapter presents a comparison between the wind-wave energy at each of the study sites described in Chapter IV for the year of observations (October 1978 thru October 1979), and the wave energy in boat wakes during the summer of 1979. This information was produced as part of the study in order to interpret the seasonal appearance of the shoreline profiles at each of the study sites. A discussion of the association between the wave energy budgets and the fastland response is contained in Chapter IX.

A relatively easy way to compare the potential for shore erosion from boat wakes and wind waves is to compare the wave energies from each source. Wave energy is simply proportional to the square of the wave heights. However, a single value of the magnitude of wave energy within a given hour does not explain how that energy may have been distributed within that hour. For example, a few large waves in an otherwise calm hour would contain the same energy as a greater number of smaller waves during the hour. Even a very small wave of 0.1 foot is capable of moving sand when it breaks on the beach, but its zone of influence on the shoreline profile is small.

A larger wave, say 0.5 foot, has the capacity to move more sand per unit area over a larger area.

For this study, the field measurements were used to construct models of the total energy contained in boat wakes and wind waves. In spite of the fact that information on the individual waves is lost when the boat-wake and wind-wave energy budgets are drawn, the expression of energy provides an index for the capacity of boats and the wind to do work on the shoreline profile.

B. Methods

It is important to realize that the values presented for total wind- and boat-wake energies are estimates. A complete portrayal of the wave energy at each site would have required continuous measurement of the waves at each site which was well beyond the scope of the present study. The principal steps involved in the calculation of the boat-wake energy budget were:

1.) Develop for each site the regression relationship between hourly boating frequency and total boat-wake energy per hour. This relationship allows the simple estimation of hourly wake energy from the hourly boating frequency.

2.) Establish the duration of the boating season. This was assumed to extend from 15 May through 15 September. The data obtained in the boating inventory (Chapter VI) indicated a dramatic decrease in boating after about 20 August. Thus two levels of boating activity were assumed to apply: a high level between 10 June and 20 August, and a lower "transition" level between 15 May - 9 June and between 21 August - 15 September.

3.) Establish the average hourly boating frequency for both weekdays and weekends at each site. This was achieved by separately averaging, at each site, the weekday and weekend hourly boating frequencies observed during the inventory of boating activity. In order to describe the higher levels of activity, the values and the averaging was restricted to those observations between 10 July and 20 August. The transition periods (15 May - 9 June and 21 August -15 September) were assumed to contain one-half the hourly boating frequency described during July and August.

4.) For the purposes of computation, the period of boating activity each day was taken as 8 hours. This is reasonably consistent with the observations that most boating occurred between mid-morning and very late afternoon or early evening.

5.) Following steps (1) through (4), the wave energy due to boat wakes was then calculated on a monthly basis and also for the periods between surveys of the shoreline.

i. <u>Boat Wake Energy Calculations</u>

Analyses from the initial 13-day observation period indicated that the <u>hourly</u> boat wake energy was linearly correlated with hourly boat frequency at each of the five sites (Figures 7.1 to 7.5). When boat traffic was light, the signatures of individual boat passes could be discriminated in the record. In these cases, the hourly boat-wake energy was simply the sum of the energies in individual boat passes during the hour. When the boat traffic was so heavy that it was not possible to discriminate individual boat passes, the wave recorder was turned on for 15 minutes each one-half hour so that battery energy would be conserved, thereby insuring the capability of the instrument to measure waves throughout the day. In these situations, the hourly wave energy was calculated as a multiple of the wave energy contained within the 15 minute segements. But the frequency of boat passes and other characteristics of each passing boat were still continuously recorded on the log sheets.

The actual energy of a wave is directly proportional to the square of the wave height. The total energy contained in each boat wake reaching the shore was calculated as:

$$E_B = \frac{1}{8}\rho g N H^2{}_{rms} \qquad 7.1$$

where N = Number of boat waves recorded

H_{rms} = Mean square wave height

$= (\Sigma H^2/N_i)^{1/2}, \quad i=1,2,...,N$

ρg = Specific gravity of water

$= 62.5\ lbs/ft^3$

The energy given by equation 7.1 requires an adjustment for background energy due to wind waves if any are present. Wind-wave energy contributions were determined from samples of wind waves taken during the absence of boats approximately at the beginning of each hour. Using equation 7.1 together with the number of wind waves present in the sample, an energy "C_w" is calculated as an estimate of the wind-wave energy contribution during subsequent boat-wake events:

$$C_w = E_w \Delta t_B / \Delta t_w \qquad 7.2$$

where Δt_b = Time duration of recorded boat wave event

Δt_w = Time duration of wind wave sample

The adjusted individual boat-wave energy is therefore $E_B' = E_B - C_w$. If two or more boat-wave trains were encountered at one time, the resultant waves are treated as a single event.

ii. Regression Analysis between Wave Energy and Boating Frequency

For the levels of boating activity and boat-wake energies which were collected at the study sites, a line of best fit to the data collected at each site was calculated using linear regression through the origin (Table 7.1, Figures 7.1 thru 7.5). Regression through the origin is required since boat-wake energy must approach zero as the number of boat passes approaches zero. The model for this regression is:

$$E_H = \beta f_H + \varepsilon \qquad 7.3$$

where E_H = Total boat energy for a given hour

f_H = Frequency of boat passes during the hour

β = Regression coefficient

ε = Deviation from regression

opposite: Table 7.1 (top) Results of regression analysis: hourly boat-wake energy as a function of hourly boating frequency.

Figure 7.1 (bottom) Regression curve for boating and wake energy at Site A.

next pages: Figures 7.2 to 7.5 Regression curves for boating and wake energy at Sites B thru E.

Results of Regression Analysis: Hourly Boat Wake Energy as a Function of Hourly Boating Frequency, $\hat{E}_H = b\ f_H$.

Site	Regression Equation	Confidence Interval Estimate on Regression Coefficient	Sample Standard Deviation from Regression, $S_{E \cdot f}$
A	$\hat{E}_H = 4.89\ f_H$	$\pm$ 0.73	3.84
	$\hat{E}_H = 3.24\ f_H$	$\pm$ 0.71	7.47
	$\hat{E}_H = 2.24\ f_H$	$\pm$ 0.46	3.69
B	$\hat{E}_H = 2.82\ f_H$	$\pm$ 0.47	5.98
C	$\hat{E}_H = 15.78\ f_H$	$\pm$ 1.47	22.95
D	$\hat{E}_H = 10.64\ f_H$	$\pm$ 1.14	18.86
E	$\hat{E}_H = 2.27\ f_H$	$\pm$ 0.34	2.95

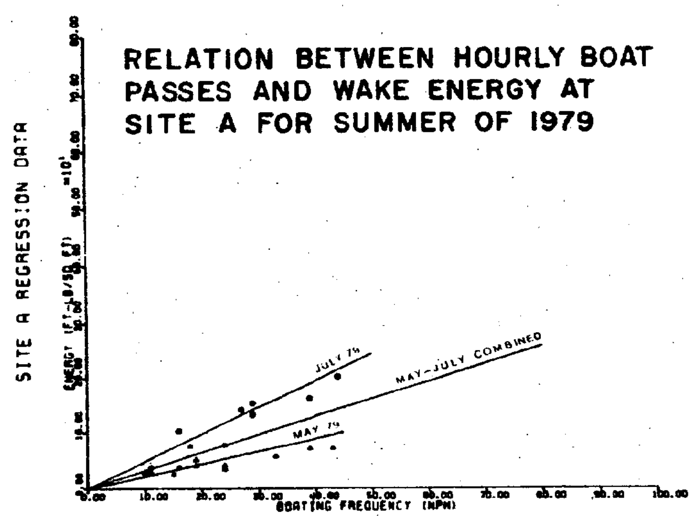

Figure 7.1

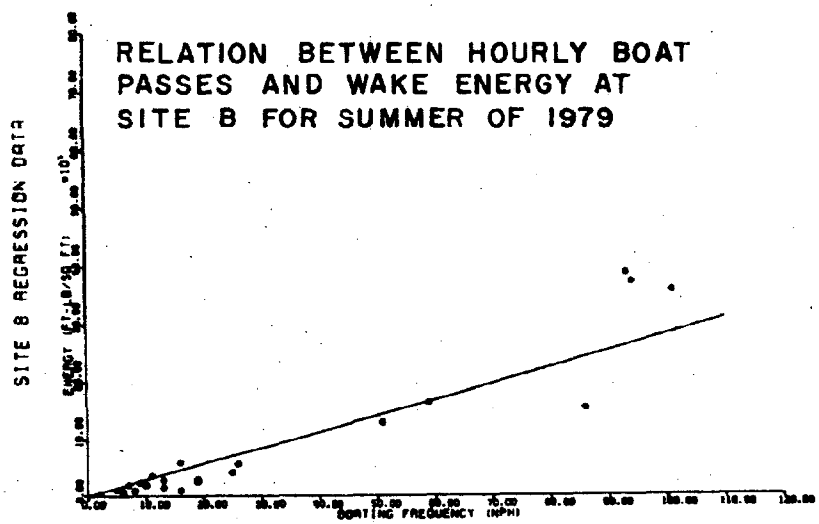

Figure 7.2

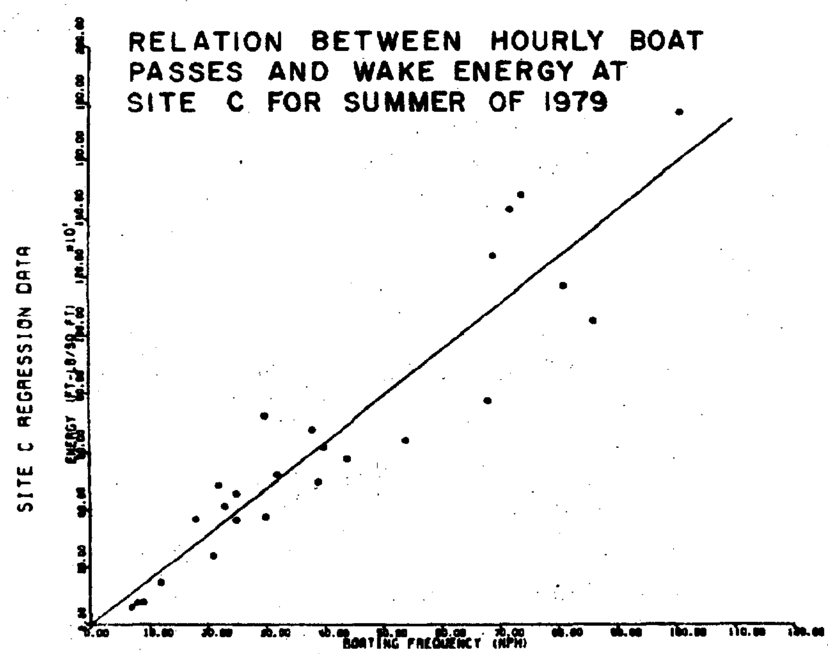

Figure 7.3

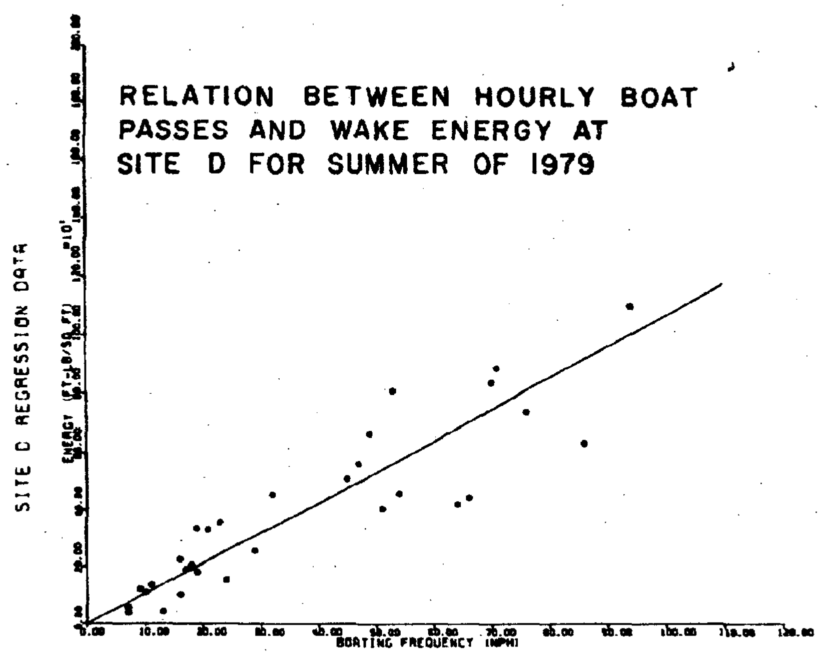

Figure 7.4

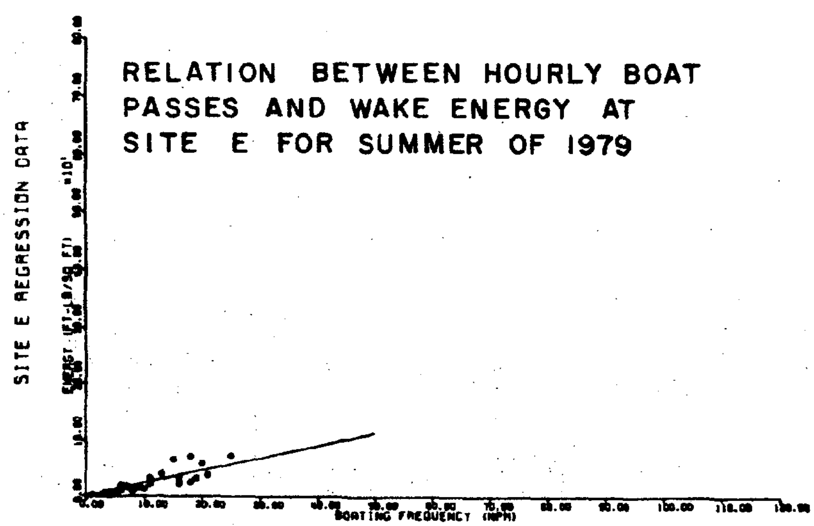

Figure 7.5

For the purposes of this study, an extended form of this model was constructed where the variance of ϵ is assumed to be directly proportional to the value of f_H. Using the assumption, β is then estimated by the sample regression coefficient "b", which is computed as "b" = $E_H / f_H = \bar{E}_H / \bar{f}_H$.

Obviously, the use of the model for obtaining daily boat-wake energy assumes that the mixtures of boating characteristics remains consistent throughout the boating season, and that the sample data are unbiased. The primary benefit of the model is that it enables the prediction of boat-wake energy to extend to all days during which the fundamental variable of boating frequency had been measured.

Regression analyses were performed for each site using samples from the data acquired throughout the boating season. The results of the regression analyses are presented in Table 7.1 and shown in Figures 7.1 through 7.5. Table 7.1 contains the indiviudal regression estimates for each site, the sample standard deviation from regression ($S_{E \cdot f}$), and a confidence interval estimate on the regression coefficient ($S_b \, t_{.05}$) using Student's "t" at an alpha level of 0.05.

Multiple regression equations were developed for Site A since this site was exposed to wave energies arising from boat traffic using both Harness Creek and South River. Table 6.2 indicates that on weekends approximately 65% of the passes were associated with South River traffic, but the level dropped to 46% on weekdays. The three regression lines described in Figure 7.1 (and Table 7.1) represent conditions reflecting the different proportions of traffic on South River. The upper curve (July '79) was derived from data samples on the 6th, 11th and 31st of July when only about 25% of the passes were in South River, and thus reflects the energies derived from boats relatively close to shore. The lowest regression line (May '79) represents sample from two days in late May when the majority of boat passes were in the South River and the resulting wave energies reaching the site were relatively small. In the calculation of total boating energy during the boating season (which will be discussed shortly) the regression relation $E_H = 2.24\ f_H$ was used for weekend days and the "combined" regression (Figure 7.6) was used to approximate the relationship for weekdays.

iii. Average Hourly Boating Frequency and Wave Energy Due to Boats

The regression analyses discussed above enable the hourly boat-wave energy to be estimated from the hourly boating frequency At each site, a number of weekdays and weekend days were inventoried during the boating season (Table 6.1). For each of these days an average hourly boating frequency was calculated (Table 6.1 and Figure 7.6). Examination of Figure 7.6 shows that during the latter part of August and during September the average hourly frequency had diminished relative to the mid-summer period. Although there are fewer observation days in late May and early June, there is also a suggestion that the average hourly frequencies were also less in this early part of the boating season. These periods of diminished activity can be predicted since the local schools recess for summer in early June and return in late August.

For the purpose of estimating the average hourly "mid-summer" boating frequency at each site, the period between 10 June and 20 August was used. The weekday and weekend hourly boating frequencies were separately averaged. It was then assumed that the "transition" periods were characterized by one-half of the respective "mid-summer" levels.

The boating season was assumed to start on 15 May and to end 15 September. Thus the transition periods were 15 May-to-9 June and 21 August-to-15 September. The average hourly boating frequencies so derived are listed in Table 7.2.

The total wave energy in any monthly period (or profile period) is estimated by the hourly wave energy at each site

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<u>opposite:</u> <u>Figure 7.6</u> Graph of average hourly boating frequencies at the five study sites.

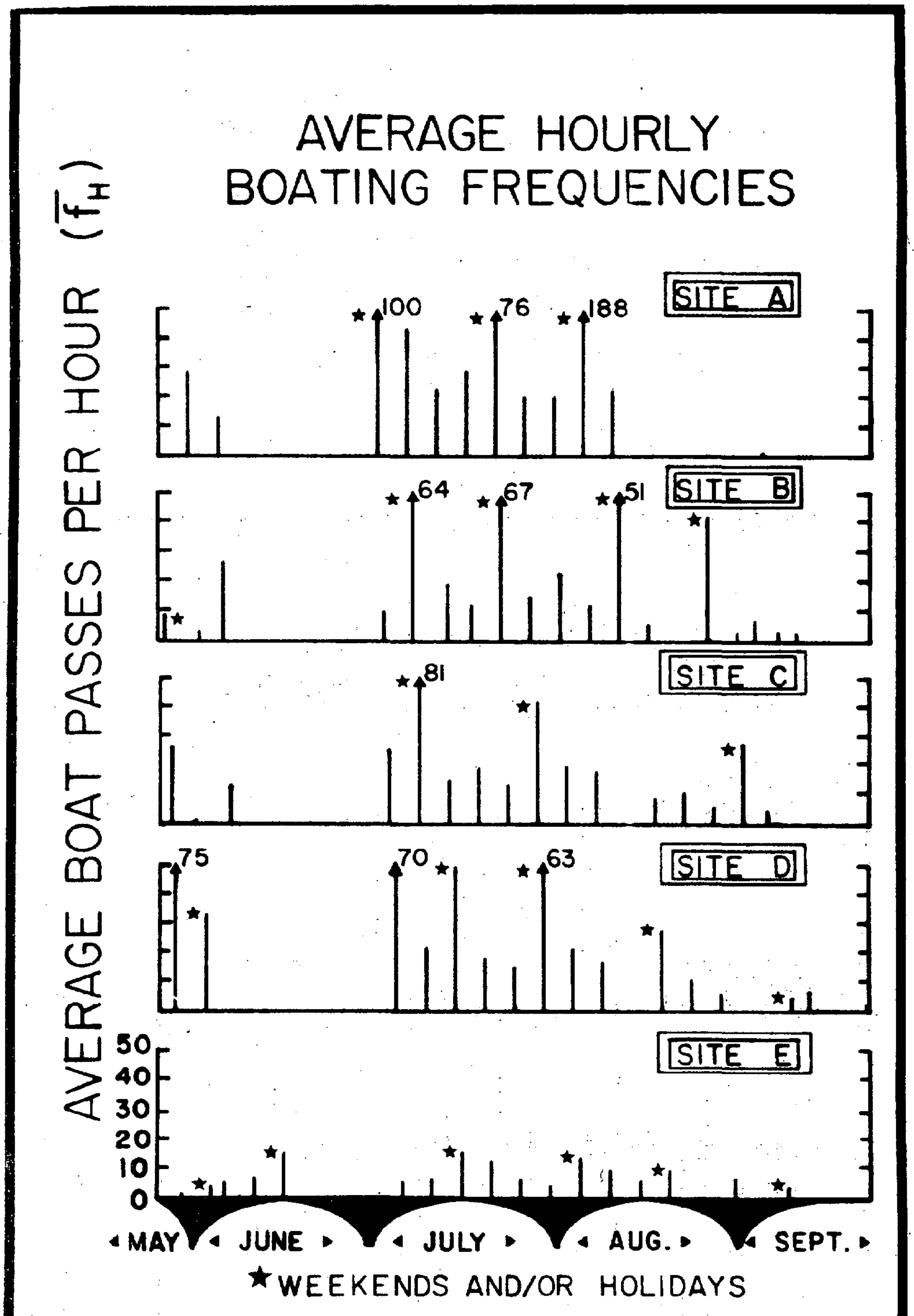
AVERAGE HOURLY
BOATING FREQUENCIES
AVERAGE BOAT PASSES PER HOUR ($\bar{f}_H$)
SITE A
100
76
188
SITE B
64
67
51
SITE C
81
SITE D
75
70
63
SITE E
50
40
30
20
10
0
MAY
JUNE
JULY
AUG.
SEPT.
★WEEKENDS AND/OR HOLIDAYS

Figure 7.6

TABLE 7.2 Comparison of Wave Energies for Year and Boating Season

Site	YEARLY SUMMARY Rank Wind Wave	Wind Wave Energy ($ft-lbs/ft^2$)	Boat Wake Energy ($ft-lbs/ft^2$)	Percent Boat Wave Energy	BOATING SEASON Rank Wind Wave	*Wind Wave Energy ($ft-lbs/ft^2$)	Boat Wave Energy ($ft-lbs/ft^2$)	Rank Boat Wave	Percent Boat Wave Energy	% Wind Wave in Boating Season
A	2	5,450,816	118,100	2.2 (1)	2	2,651,077	118,100	3	4.4 (2)	49 (3)
B	3	4,133,173	70,680	1.7	3	1,938,797	70,680	4	3.6	47
C	4	3,823,991	376,040	9.6	4	1,847,511	376,040	1	20.4	48
D	1	6,969,310	247,660	3.6	1	2,948,847	247,660	2	8.4	42
E	5	3,181,249	15,650	0.5	5	1,756,115	15,650	5	0.9	55

*Summed for entire months of May through September, 1979

(1) Percent Boat Wave Energy = (Boat Wake Energy ÷ year total wind wave energy) x 100

(2) Percent boat wave energy = (boat wake energy ÷ boat season wind wave energy) x 100

(3) Percent wind wave in boating season = (wind wave in boating season ÷ year total wind wave energy) x 100

multiplied by the number of days (weekdays and weekend days) and by the number of boating hours per day (which was assumed to be 8 hours).

C. Results

The values for wave energy from wind waves and boat wakes for the year and for the boating season are shown in Table 7.2, together with the relative magnitudes. With respect to wind-wave activity, the sites rank (in decreasing order) D, A, B, C, E for both the total year, and the 1979 "boating season". The sites range C, D, A, B, E with respect to boat-wake energy.

Site C exhibited the highest (20.4%) percentage of boat wake energy during the boating season. Note that Figure 7.7 shows boats were not the principal source of wave energy at any of the shoreline sites during the summer months. Nearly one-half (42-55%) of the total annual wind wave energy occurred during the boating season (May-September).

Monthly summaries of the wind- and boat-wave energies are given in Table 7.3 and Figure 7.7. A summary between

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opposite: Table 7.2 Comparison of Wave Energies for the Year and Boating Season.

next pages Table 7.3 Wind-wave and boat-wake energy budgets at each site between profile periods.

Table 7.4 (left) Wind-wave and boat-wake energy budgets at each site by month.

Table 7.3 Wind-Wave and Boat-Wake Energy, ft-lbs/ft^2 by Profile Period

Period	SITE A	B	C	D	E
10/29/78-11/25/78	357,845	361,120	241,211	390,062	227,638
11/25/78-12/20/78	397,659	292,156	223,281	409,392	172,665
12/20/78-2/3/79	501,347	388,154	350,278	1,069,687	219,930
2/3/79-3/10/79	36,737	25,469	244,837	512,135	28,905
3/10/79-4/15/79	637,492	526,448	383,118	690,178	334,576
4/15/79-5/25/79	571,142	460,157	435,388	651,301	381,474
5/25/79-6/23/79	529,469	297,318	348,538	556,232	297,539
Boat	43,080	14,160	83,850	56,240	3,560
%	8.1	4.8	24.1	10.1	1.1
6/23/79-7/28/79	538,453	400,853	374,921	610,303	347,469
Boat	56,260	23,240	137,080	90,750	5,720
%	10.4	5.8	36.6	14.9	1.6
7/28/79-8/18/79	369,195	310,968	236,258	408,779	220,484
Boat	32,030	13,300	78,880	53,280	3,370
%	8.7	4.3	33.4	13.0	1.5
8/18/79-9/15/79	578,233	426,361	411,982	670,357	437,187
Boat	17,820	9,400	65,400	36,500	2,300
%	3.1	2.2	15.9	5.4	0.5
9/15/79-10/20/79	721,058	518,193	451,789	770,309	422,181

% Boat Energy = Boat Energy ÷ Wind Wave Energy x 100

Table 7.4 Wind-Wave and Boat-Wake Energy, ft-lbs/ft^2; by Month

Month	SITE A	B	C	D	E
Nov,'78	368,876	382,030	243,274	401,653	231,533
Dec,'78	568,327	397,942	302,422	580,851	232,657
Jan,'79	286,499	220,384	203,256	729,965	131,259
Feb,'79	0	0	241,940	459,637	0
Mar,'79	426,045	290,674	284,571	582,364	240,740
Apr,'79	449,694	436,867	282,900	501,979	244,569
May,'79	494,260	333,635	373,589	550,673	327,697
*Boat	9,200	4,750	28,450	19,740	1,250
% Boat	1.9	1.4	7.6	3.6	.04
June,'79	525,098	297,350	367,197	572,675	320,864
Boat	31,200	25,170	96,980	65,120	4,110
% Boat	5.9	8.5	26.4	11.4	1.3
July,'79	453,541	377,932	303,306	512,831	286,220
Boat	37,700	19,790	117,250	78,940	4,990
% Boat	8.3	5.2	38.7	15.4	1.7
Aug,'79	591,475	443,806	407,363	663,395	397,749
Boat	30,300	15,840	94,180	64,130	4,060
% Boat	5.1	3.6	23.1	9.7	1.0
Sep,'79	586,703	486,024	396,056	649,273	423,585
**Boat	9,700	5,130	30,180	19,730	1,240
% Boat	1.6	1.0	7.6	3.0	0.3
Oct,'79	697,298	466,529	418,117	764,014	344,376

* Boating Energy Based on 15 May - 31 May

** Boating Energy Based on 1 Sept. - 15 Sept.

% Boat Energy = Boat Energy ÷ Wind Wave Energy x 100 profile periods is given in Table 7.2. The zero entries for wave energy at Sites A, B, and E during February, 1979 represent ice-bound conditions. A relatively strong contribution from boat-wake energy at Site C is shown in Figure 7.7. In July 1979, boat-wake energy was 38.7% of the wind-wave energy (27.9% of the total wave energy (Figure 7.7).

It is of interest to compare Sites B and C. Both sites were subject to essentially the same levels of wind energies with the same percentage of that activity occurring during the boating season (47-48%). Inspection of Table 6.2 indicates the two sites have very similar levels of boating activity and about the same ratios of planning versus displacement hulls. Site C had a somewhat higher percentage of water-skiing activity (45% versus 60%). The major difference in the boating activity at the two sites was the distance of the boat passes relative to the shore. At Site B about 80% of the boat passes were at distances

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next page: Figure 7.7 Histograms of monthly wave energy. Open boxes represent wind-wave energy and blocked boxes represent boat-wake energy. The values entered above the boat-wake energy represent the fraction of boat-wake energy relative to the total (wind plus boat) energy for the month.

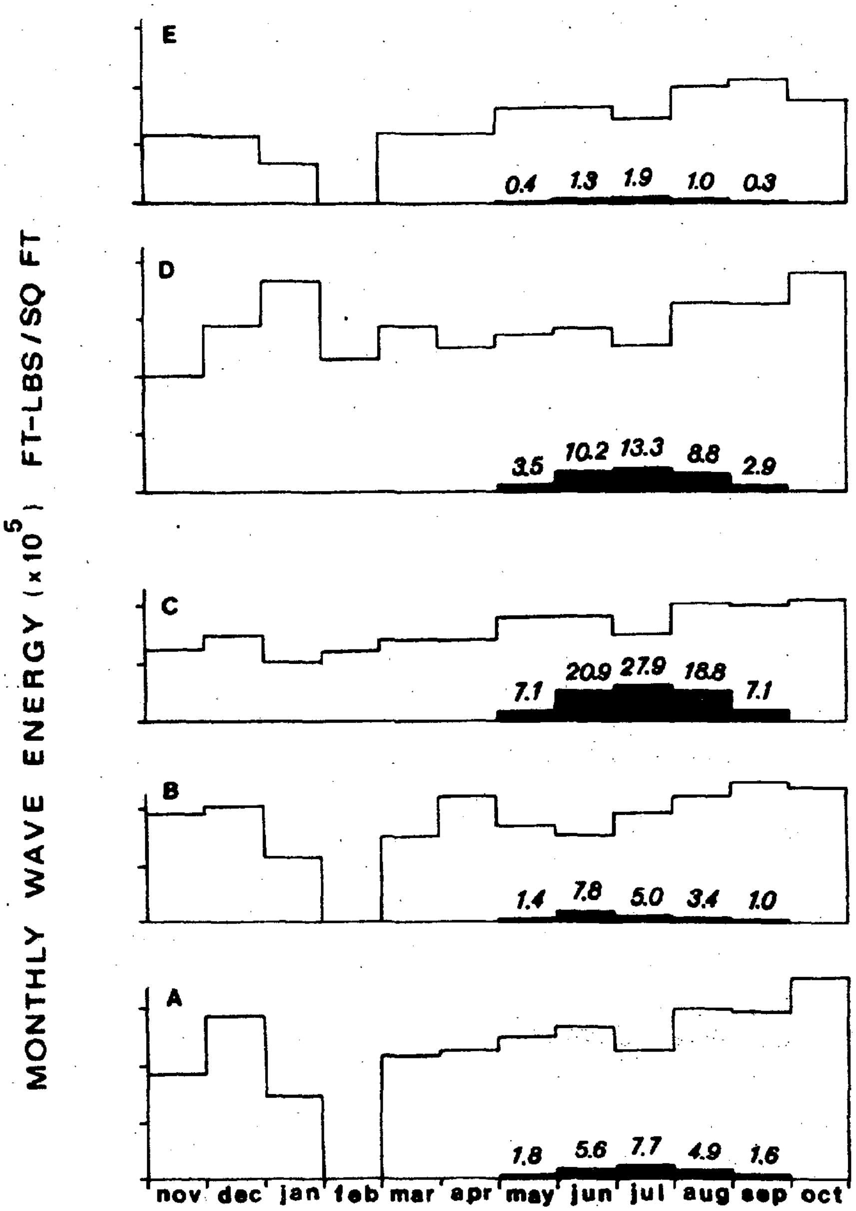
MONTHLY WAVE ENERGY (x10^5) FT-LBS/SQ FT
E
0.4 1.3 1.9 1.0 0.3
D
3.5 10.2 13.3 8.8 2.9
C
7.1 20.9 27.9 18.8 7.1
B
1.4 7.8 5.0 3.4 1.0
A
1.8 5.6 7.7 4.9 1.6
nov dec jan feb mar apr may jun jul aug sep oct

Figure 7.7

greater than 500 feet whereas at Site C over 80% of the boat passes were at distances less than 200 feet. It thus appears that the close proximity of passage at Site C is the principal cause of the relatively high boat-wake energies. In addition, the steeper nearshore bottom gradient at Site C results in less frictional influence on the incoming waves.

VIII

WAVES GENERATED BY PASSAGE OF A BOAT

Robert J. Byrne, John D. Boon III,
Rhonda Waller, and Deborah Blades

A. Introduction

This chapter presents the results of a modest experiment conducted at one of the study sites to understand the behavior of wakes produced by boats cruising at different speeds and distances from the shoreline.

As a boat passes over the water's surface, part of the energy transmitted by the craft's propulsion unit is taken up by the water in the form of surface waves. Thus, the wakes are a manifestation of the resistance offered by the still water to the deformation caused by the boat's hull. The earliest studies of the waves caused by ships were conducted from the viewpoint of how waves effect the resistance of a ship (Froude, 1881; Kelvin, 1887). More recently, attention has been devoted to the relation between ship waves and the stability of banks on the waterways through which the boats pass (Johnson, 1957; Das, 1969; Sorenson, 1967).

The pattern of waves in a boat wake depends partially on the value of the Froude number "F"* (which is the ratio

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*The Froude Number is not directly measurable, but represents the ratio of two variables which often become "lumped together" in theoretical wave-energy equations. The Froude Number "F" is the ratio of the boat speed "V_s" and the speed "C" of a wave in shallow water. The wave speed is in turn a function of the basin depth "d", since $C = \sqrt{gd}$. ("g" is the acceleration due to gravity; "g" = 32 feet/sec.^{2}). So... Froude Number "F" = $V_s/\sqrt{gd}$.

between the boat speed "V_s", and the speed "C" of a wave in shallow water). Both the Froude number and the configuration of a boat hull influence the maximum wave height which will be experienced at a given distance from the sailing line of the boat.

A displacement hull will generate a series of waves at the bow and stern (Figure 8.1). At values of "F" below 1, the wave pattern in the vicinity of the boat, together with the maximum wave height, can change fairly dramatically as the wake travels away from the boat. Each set of waves produced at the bow and stern include a series of waves diverging from the sailing line and a series of transverse waves which move in the direction of boat passage. The intersections of the transverse and diverging waves are points of higher wave heights where breaking waves are most likely to occur in the wake.

These "cusp" locations may be connected to form a locus of cusps which define an angle "Ø" which the wave front makes with the sailing line (Figure 8.1). The theoretical development of Kelvin (1887) predicts a value of Ø = 19°28' for Froude number values less than 0.7 and for values greater than about 3. However, for intermediate "F" values, the angle "Ø" approaches a maximum of 90° when "F"=1. At this point the transverse and diverging waves combine to

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opposite: Figure 8.1 (top) Schematic drawing of waves generated by moving boat.

Figure 8.2 (bottom) Definition sketch of boat wake packet.

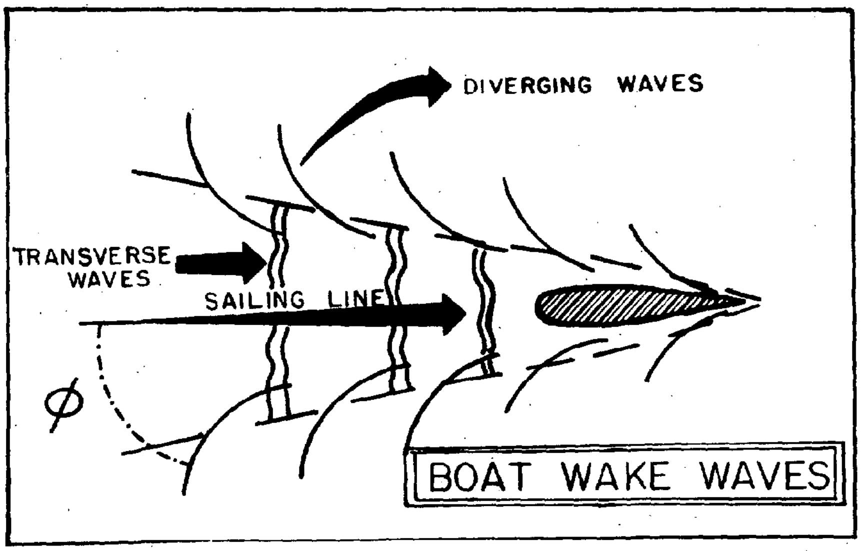

Figure 8.1

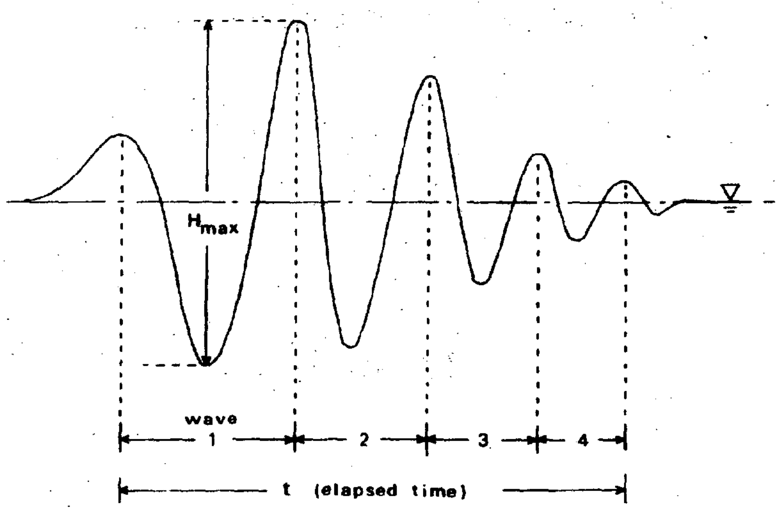

Figure 8.2

form a single wave with its crest normal to the sailing line.

Besides the angle $\emptyset$, the maximum wave height (and thus total energy) in the wake wave "packet" varies with the Froude number. A typical boat-wake wave packet is shown schematically in Figure 8.2. Within the packet there is a single wave with maximum height. Results of some experiments with boat models in a towing tank (Johnson, 1957) are shown in Figure 8.3 to illustrate the nonlinear behavior of "H_{max}" with Froude number "F". After passing the critical value of "F", the values of "H_{max}" tend to approach a constant value.

B. Field Measurements of Controlled Boat Passes

The experiment was conducted at Site C (Broad Creek), using boats operated by the Maryland Department of Natural Resources Marine Police. Two boats were used: a 26 ft. Uniflite cruiser (Marine Police boat "Somerset"), and a 16 ft. Boston Whaler. The Uniflite is a deep-V planing hull while the Boston Whaler is a 3-point planing hull. Replicate passes were made at distances of 200, 150, and 100 ft. (also 50 ft. in the case of the Whaler) from the shoreline for a range of speeds between 6 and 30

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opposite: Figure 8.3 (top) Maximum wave height as a function of Froude Number for typical ship model (Johnson, 1957).

Figure 8.4 (bottom) Typical record of boat wake passing the wave gage in shallow water.

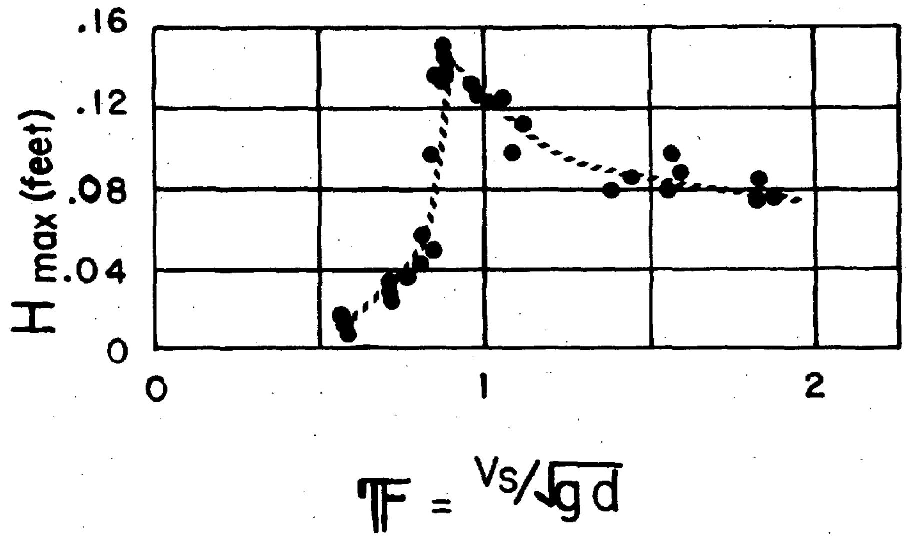

Figure 8.3

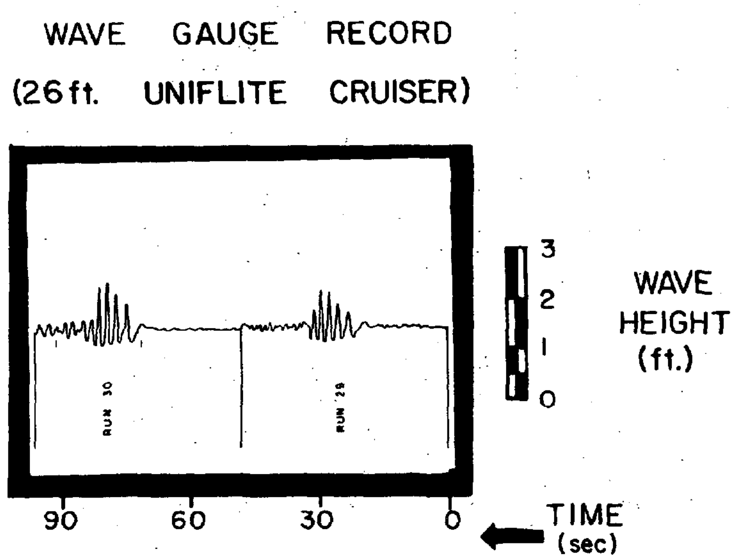

Figure 8.4

knots. Boat speed was determined by measuring the time for the boat to travel between two buoys anchored 100 ft. apart. The surface wave gauge (described in Appendix A) was located approximately 24 feet from the shoreline in a water depth of about 2.2 feet. With very rare exception none of the waves in the generated trains broke seaward of the wave gauge position. A typical wave record produced during the trial runs is shown in Figure 8.4.

The results of the experiment are shown in Tables 8.1 and 8.2. In these calculations several different parameters are of interest. These are:

"H_{max}" = the highest wave of the group (measured in feet).

"$\bar{T}$" = the average wave period (defined as the number of waves divided into the duration of the wave packet).

"$\bar{E}$" = average energy per unit surface area ($ft\text{-}lbs/ft^2$)

$$= \frac{1}{8} \rho g H^2_{rms}, \text{ where } "H_{rms}" = (\Sigma\, H^2/N_i)^{1/2} \quad i = 1,2,\ldots,N$$

"E_T" = total energy in wave train ($ft\text{-}lbs/ft^2$)

$$= \frac{1}{8} \rho g N H^2{}_{rms}$$

"F" = $1.667\ V_s/\sqrt{gd}$ for boat speed in knots.

The results of the trial runs are graphed in Figures 8.5 thru 8.12. In the plot of "F" versus "H_{max}" (Figures 8.5 and 8.6), there is an apparent peak in "H_{max}" at values of "F" between 0.8 to 1.0. A definite relation of "H_{max}" to the distance of the boat from the shore is also apparent, and this relationship is stronger for the deep-V hull. Figures 8.7 and 8.8, which are of boat speed versus "H_{max}", offer a simpler illustration of how "H_{max}" varies with different boat speeds. As expected, the deep-V hull of the 26 ft. cruiser generated the larger waves. The largest "H_{max}" occurred for speeds between 8 and 10 knots when the cruiser was in the displacement mode, and the "H_{max}" values ranged between 1.25 and 1.75 ft. for the distances tested. These values far exceed those which were expected for wind-generated waves.

It is of interest to note that the dependence of "H_{max}" (or energy, Table 8.1) upon boat speed is highly nonlinear. For the circumstances tested, "H_{max}" varies in a nonlinear fashion with the inverse of speed. The "H_{max}" for the Uniflite cruiser decreased as the boat speed was increased beyond a "critical" value of 8 to 10 knots. In the case of the 16 ft. planing hull of the Boston Whaler, the "critical" speed occurred between 6 and 8 knots when the Whaler was in the displacement mode.

For distances of 100 to 200 ft. from the shoreline, the data in Figure 8.5 show there is little dependence for either the Whaler or the Uniflite Cruiser between "H_{max}" and the distance of the boat from shore. However, at the closer boat passes of 50 ft., the range of "H_{max}" is dramatically increased. Again the nonlinear dependence of

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next pages: Tables 8.1 and 8.2 Summary of observations of controlled boat passes.

Table 8.1 Summary of Observations: 26 ft. Uniflight Cruiser

Run	Speed MPH	Speed Knots	Distance (ft.)	Number of Waves	H_m (ft.)	$\overline{E}$ (ft-lb/ft^2)	E_T (ft-lb/ft^2)	Duration t (sec)	$\overline{T}$ (sec)	F (V in knots)
11	28.4	24.9	200*	15	0.58	1.09	16.35	34.2	2.3	2.04
12	31.0	27.3	200	15	0.58	1.08	16.20	33.0	2.2	2.23
13	23.5	20.7	200	17	0.74	1.36	23.12	39.0	2.3	1.69
14	20.0	17.6	200	19	0.85	1.41	26.79	41.1	2.2	1.44
15	8.6	7.6	200	15	1.30	2.75	41.25	38.1	2.5	0.62
16	10.2	9.0	200	15	1.81	4.71	70.65	45.0	3.0	0.74
17	6.3	5.5	200	17	0.56	0.48	8.16	28.2	1.7	0.45
18	6.5	5.7	200	17	0.71	0.53	9.01	24.3	1.4	0.47
19	32.5	28.6	150	17	0.67	1.06	18.02	37.8	2.2	2.43
20	31.0	27.3	150	17	0.69	1.09	18.53	33.9	2.0	2.32
21**	20.7	18.2	150	9	1.12	4.08	36.72	21.6	2.4	1.55
22**	20.7	18.2	150	11	0.96	2.99	32.89	25.2	2.3	1.55
23**	9.6	8.4	150	11	1.58	4.64	51.04	30.0	2.7	0.71
24	13.6	12.0	150	9	0.98	4.25	38.25	22.2	2.5	1.02
25	11.8	10.4	150	9	1.23	6.04	54.36	26.4	2.9	0.88
26	6.4	5.6	150	6	0.60	1.13	6.78	9.0	1.5	0.48
27	6.8	6.0	150	6	0.71	1.37	8.22	9.3	1.6	0.51
28	29.6	26.0	100	6	1.03	3.76	22.56	12.9	2.2	2.42
29	29.6	26.0	100	6	0.96	3.53	21.18	14.1	2.4	2.42
30	22.0	19.4	100	9	1.14	3.81	34.29	19.8	2.2	1.81
31	20.0	17.6	100	9	1.07	3.18	28.62	18.0	2.0	1.64
32	11.0	9.7	100	6	1.36	7.50	45.00	18.3	3.1	0.90
33	11.8	10.4	100	6	1.34	7.08	42.48	19.8	3.3	0.97
34	6.6	5.8	100	9	0.71	1.05	9.45	14.7	1.6	0.54
35	6.9	6.1	100	9	0.74	1.26	11.34	18.6	2.1	0.57

** Largest wave broke just seaward of wave gage

* Water depth at 200 ft = 13 ft.
150 ft = 12 ft.
100 ft = 10 ft.
50 ft = 3 ft.

Table 8.2 Summary of Observations: 16 ft. Boston Whaler

Run	Speed MPH	Speed Knots	Distance (ft.)	Number of Waves	H_m (ft.)	$\overline{E}$ (ft-lb/ft^2)	E_T (ft-lb/ft^2)	Duration t (sec)	$\overline{T}$ (sec)	F (V in knots)
1	28.4	25.0	200	28	.179	0.11	3.08	46.8	1.7	2.04
2	32.5	28.6	200	29	.201	0.11	3.19	48.0	1.7	2.34
3	20.7	18.2	200	21	.290	0.25	5.25	36.3	1.7	1.49
4	26.2	23.0	200	25	.290	0.23	5.75	42.6	1.7	1.88
5	9.6	8.4	200	22	.335	0.38	8.36	40.2	1.8	0.69
6	11.8	10.4	200	22	.446	0.49	10.78	45.6	2.1	0.85
7	6.5	5.7	200	15	.312	0.30	4.50	24.3	1.6	0.47
8	6.9	6.1	200	19	.290	0.26	4.94	30.0	1.6	0.50
9	31.0	27.3	150	22	.246	0.15	3.30	33.9	1.5	2.32
10	31.0	27.3	150	22	.223	0.16	3.52	34.5	1.7	2.32
11	20.7	18.2	150	16	.335	0.34	5.44	27.6	1.7	1.55
12	22.0	19.4	150	17	.312	0.29	4.93	31.2	1.8	1.65
13	13.4	11.8	150	15	.468	0.55	8.25	30.9	2.1	1.00
14	9.6	8.4	150	14	.402	0.66	9.24	27.9	2.0	0.71
15	6.2	5.4	150	10	.357	0.37	3.70	17.4	1.7	0.46
16	6.5	5.7	150	10	.469	0.56	5.60	14.1	1.4	0.48
17	34.1	30.0	100	12	.312	0.31	3.72	19.8	1.7	2.79
18	32.5	28.6	100	16	.268	0.20	3.20	21.9	1.4	2.66
19	20.7	18.2	100	10	.402	0.54	5.40	17.7	1.8	1.70
20	23.5	20.7	100	11	.357	0.40	4.40	18.3	1.7	1.93
21	10.2	9.0	100	10	.513	1.00	10.00	19.5	2.0	0.84
22	11.4	10.0	100	10	.491	0.87	8.70	16.2	1.6	0.93
23	6.2	5.5	100	11	.469	0.41	4.51	20.5	1.9	0.51
24	7.9	7.0	100	10	.670	1.10	11.00	17.7	1.8	0.65
25	32.5	28.6	50	4	.491	0.80	3.20	6.0	1.5	4.86
26	17.9	15.8	50	4	.759	1.71	6.84	6.3	1.6	2.69
27	9.7	8.5	50	5	.781	1.45	7.25	9.9	2.2	1.44
28	27.3	24.0	50	5	.446	0.73	3.65	8.4	1.7	4.08
29	17.0	15.0	50	4	.670	1.30	5.20	6.0	1.5	2.55
30	11.4	10.0	50	4	.737	1.44	5.76	7.2	1.8	1.70
31	7.6	6.7	50	13	.893	0.93	12.09	31.5	2.4	1.13
32	7.2	6.3	50	14	.759	0.90	12.60	30.6	2.2	1.07
33*	23.5	20.7	200	19	.312	0.26	4.94	29.7	1.6	1.69
34*	27.2	23.9	150	16	.357	0.34	5.44	30.6	1.9	2.03
35*	27.2	23.9	50	15	.402	0.52	7.80	23.4	1.6	4.06

*with water skier

"H_{max}" and distance is shown, although "H_{max}" for the Whaler approaches a constant value beyond the "critical" speed more quickly than in the case of the deep-V hull. This is no doubt due to the fact that the planing mode is achieved at lower speeds in the Boston Whaler than in the Uniflite Cruiser.

Since the principal concern of this study is the magnitude of energy reaching the shoreline with each boat pass, plots of total wave energy "E" in the respective wave packets is shown as a function of the Froude Number "F" (with distance as a parameter) in Figures 8.9 and 8.10. The results presented above show there is a strong nonlinear relationship between "F" and "H_{max}", so it is not surprising that a similar nonlinear relationship exists between "F" and total wave packet energy at the shoreline. In the case of the deep-V hull (26 ft. Uniflite cruiser) there is only a slight suggestion that wake energy is dependent upon the distance from the shore for any given speed. In the case of the Whaler, only those boat passes at the 50 ft. distance show clear separation in their wake energies. Part of the reason for a reduction in wave energy from boats passing at greater distances from the shore is that the number of waves in a packet depends upon distance. For example, Tables 8.1 and 8.2 show that waves generated at close distance for any given speed contain higher waves but fewer in number.

It is important to note that the peak values of "E_T" and "H_{max}" in Figures 8.9 and 8.10 lie in vicinity of "F" = 0.8 rather than the theoretical value of "F" = 1. This observation is consistent with the results of similar experiments with the wakes of larger-hulled craft reported by Sorenson (1967).

Three runs were made by the Boston Whaler with a water skier in tow. This condition was tested to see in a preliminary way whether the effects of the skier's weight would cause the planing hull to "squat" and thereby generate larger "E_T" in the wake. The plot of "E_T" versus "F" (Figure 8.9) does not clearly distinguish a difference. However, a plot of "E_T" versus boat speed (Figure 8.11) suggest there may be an effect, since two of the three runs do show values for "E_T" which are higher than the general trend. While these few runs cannot be considered to display a truly significant difference, the results do suggest that the effect of water skiers on boat wakes should be examined further in future tests.

The most important observation to be drawn from these experimental boat runs is that maximum values of

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next pages: Figures 8.5 (upper left) and 8.6 (lower left) Variation in maximum wave height "H_{max}" as a function of Froude Number with distance of passage as a parameter.

Figures 8.7 (upper right) and 8.8 (lower right) Variation in maximum wave height "H_{max}" as a function of boat speed with distance of passsage as a parameter.

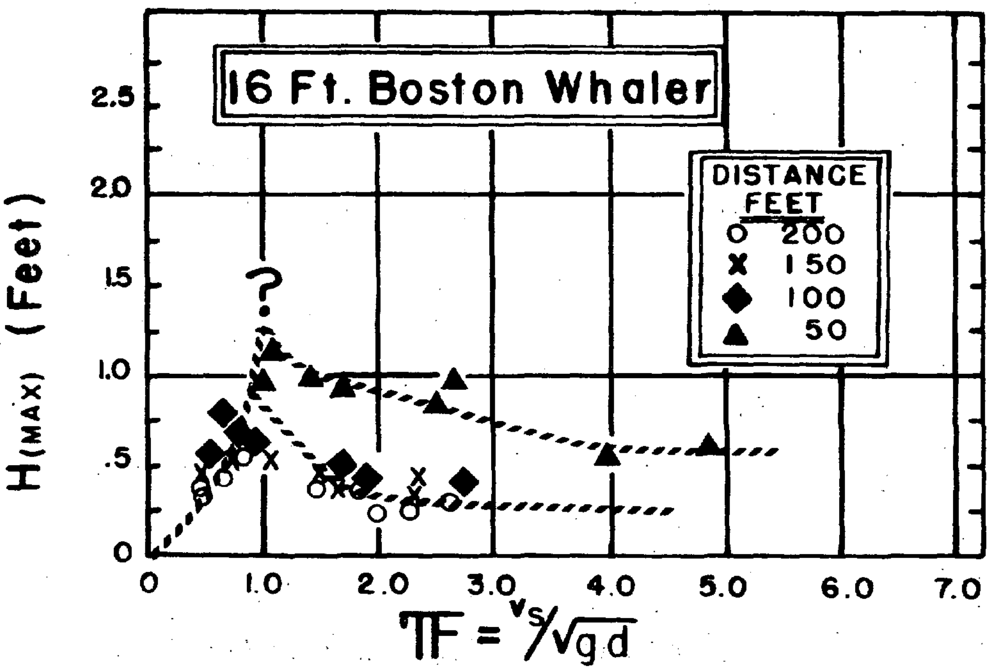

Figure 8.5

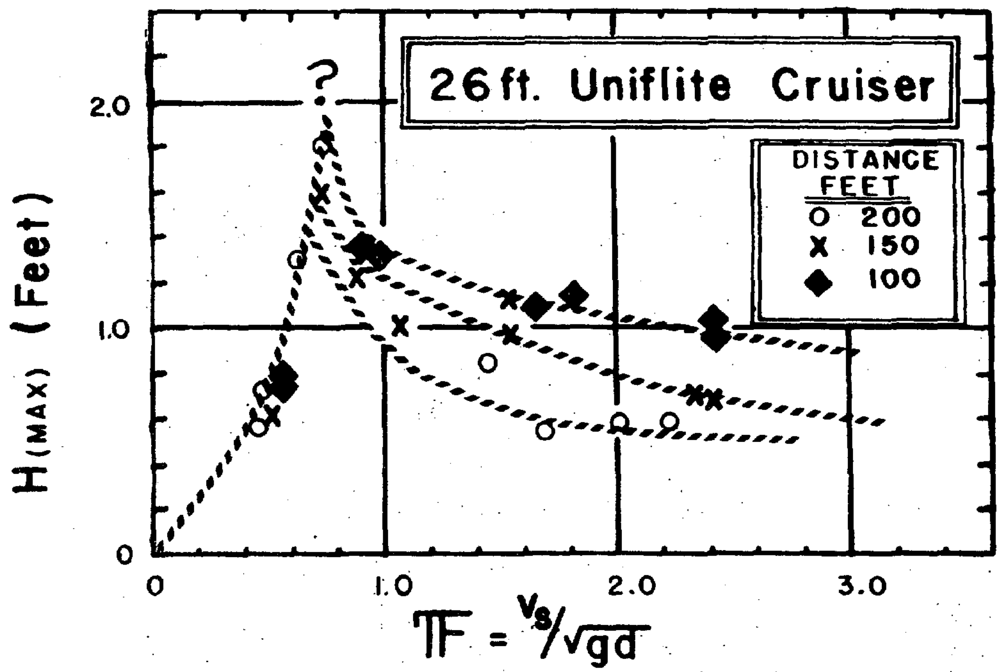

Figure 8.6

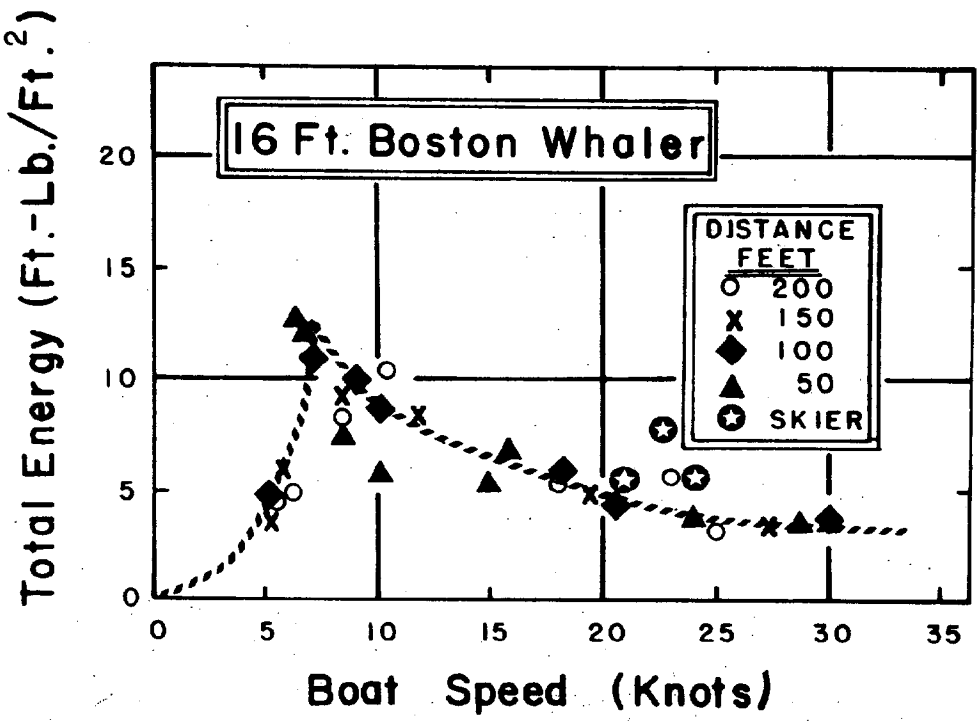

Figure 8.7

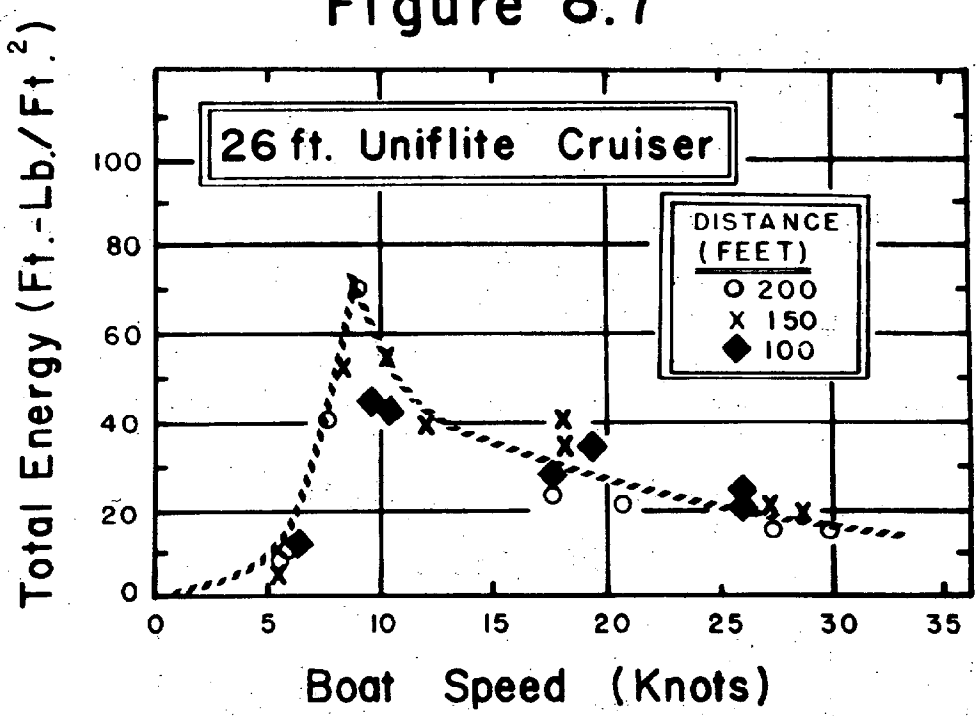

Figure 8.8

wave heights (and wake energy) are generated for Froude numbers in the range between 0.7 and 1.0. Since the Froude number is dependent upon water depth as well as boat speed, those boat speeds which generate maximum wakes will vary with different water depths in different waterways. Table 8.3, which lists the various Froude numbers arising from different combinations of boat speed and water depth, provides a simple illustration of what might be expected for a variety of "typical" conditions. For example, suppose a boat was travelling at a steady speed of 6 knots while running up a creek in which the depth decreased from 18 ft. at the mouth to 4 ft. near the head. During the run the Froude number would be small near the mouth ("F" = 0.42 to 0.56, respectively, for water depths of 18 ft. and 10 feet) and relatively small wave heights would be generated in the wake. But, when the boats reached depths less than 6 feet, the Table shows that maximum wave heights would be generated.

Table 8.3 can also be used to show the effects of another kind of boating pattern. Consider a creek where the water depth varies from 10 feet at the centerline to 2 feet

opposite: Table 8.3 Froude number for different combinations of water depth and boat speed.

next pages: Figure 8.9 (upper left) and 8.10 (lower left) Total energy in the wave packet as a function of Froude Number with distance of passage as a parameter.

Figure 8.11 (upper right) and 8.12 (lower right) Total energy in the wave packet as a function of boat speed with distance of passage as a parameter.

TABLE 8.3 FROUDE NUMBER for COMBINATIONS of WATER DEPTH and BOAT SPEED

DEPTH (ft)	SPEED (Knots) 2	4	6	8	10	12	14	16	18
2	0.42	0.83	1.25	1.66	2.08	2.49	2.91	3.32	3.74
4	0.29	0.59	0.88	1.17	1.47	1.76	2.06	2.35	2.64
6	0.24	0.48	0.72	0.96	1.20	1.44	1.68	1.92	2.16
8	0.21	0.42	0.62	0.83	1.04	1.25	1.45	1.66	1.87
10	0.18	0.37	0.56	0.74	0.93	1.11	1.30	1.49	1.67
12	0.17	0.34	0.51	0.68	0.85	1.02	1.19	1.36	1.52
14	0.16	0.31	0.47	0.63	0.78	0.94	1.10	1.26	1.41
16	0.15	0.29	0.44	0.59	0.73	0.88	1.03	1.17	1.32
18	0.14	0.28	0.42	0.55	0.69	0.83	0.97	1.11	1.25

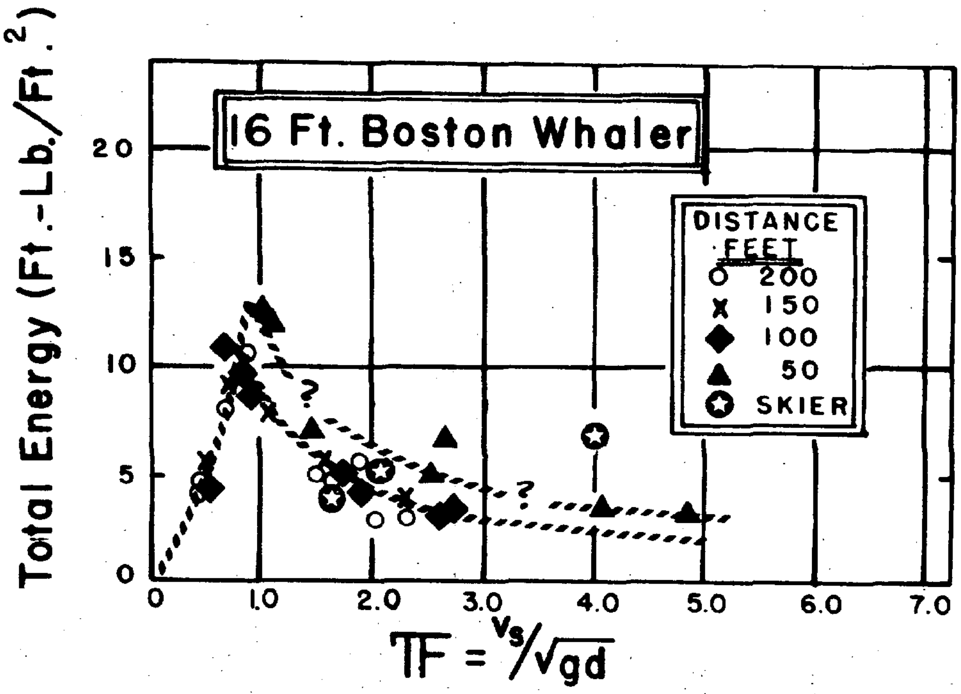

Figure 8.9

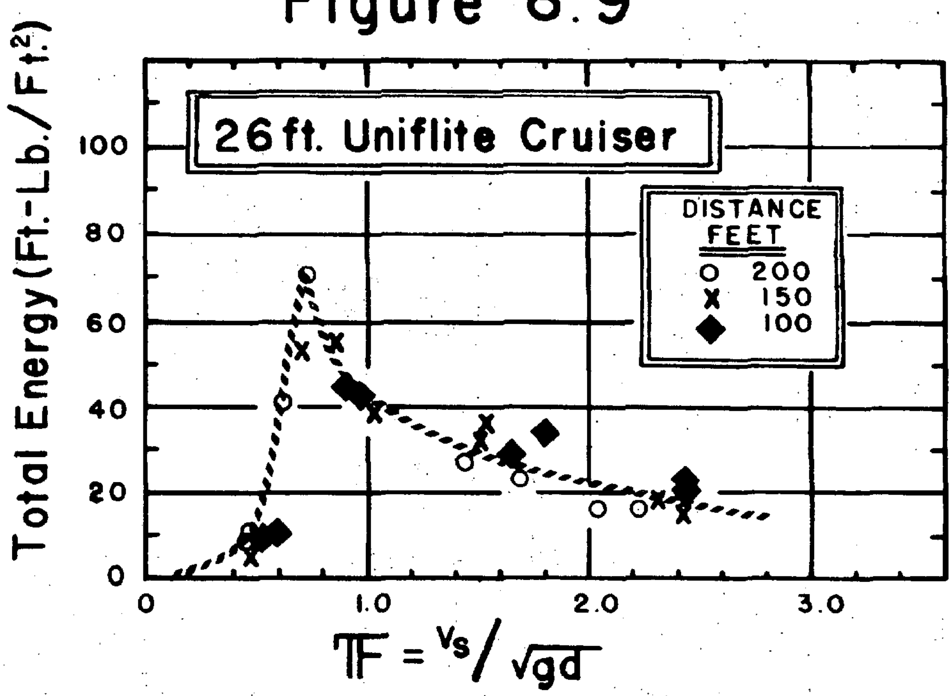

Figure 8.10

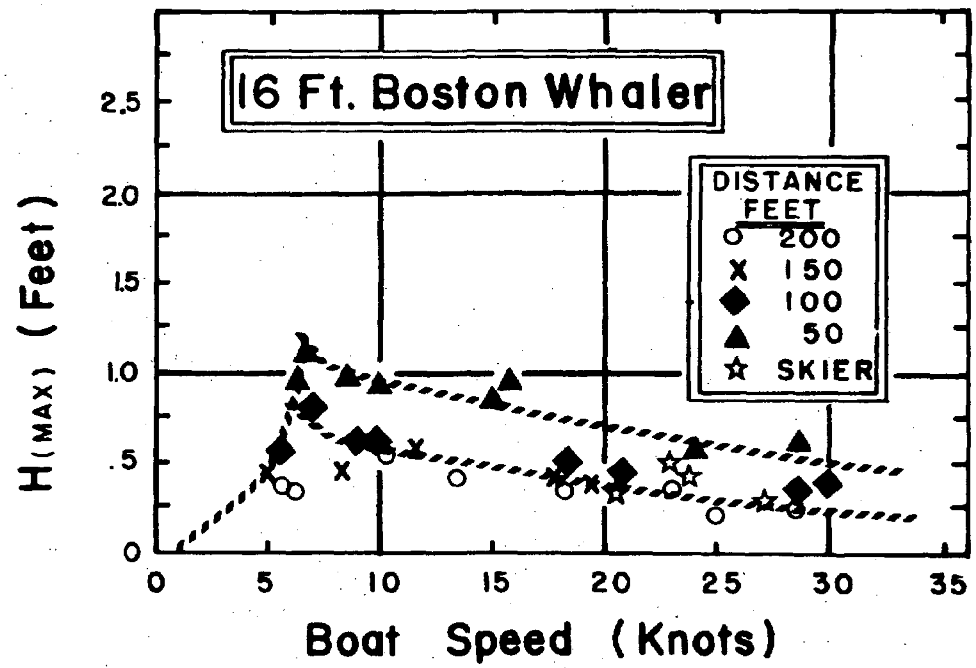

Figure 8.11

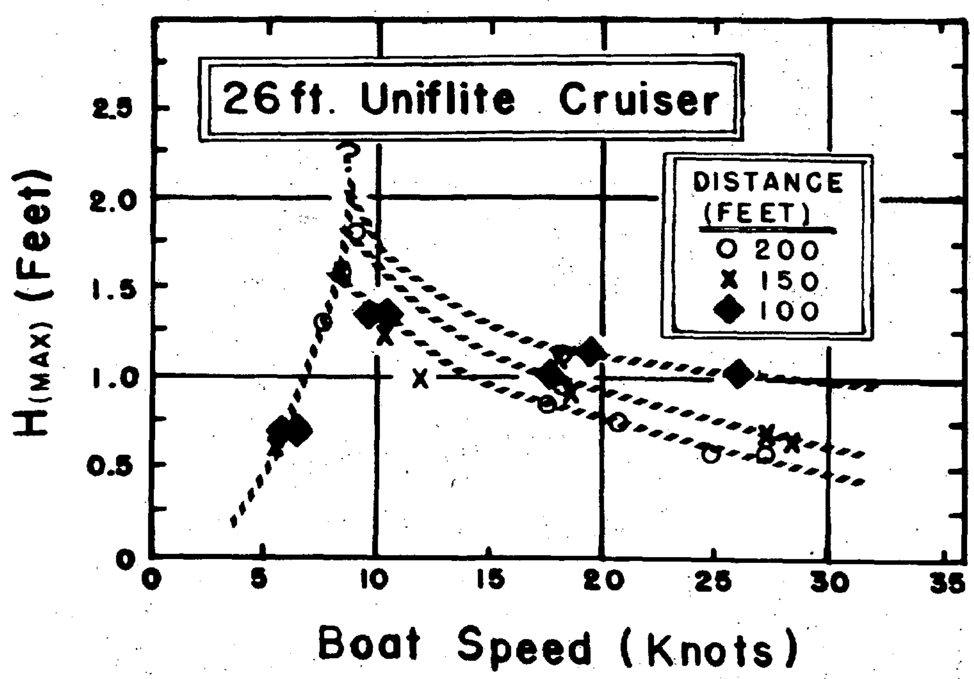

Figure 8.12

near the bank. A boat travelling the centerline at a steady speed of 6 knots would have a low Froude number (0.56) and small wake. The same boat travelling at the same speed closer to the shore in water depths of 6 feet or less would be in the Froude number range between 0.7 and 1.25 and would be generating a maximum wake.

Table 8.3 does not, unfortunately, allow for the prediction of the magnitude of the wave energy reaching the shore. The absolute magnitude of wave energy in any wake would depend upon hull characteristics and the slope of the nearshore bottom, together with the boat speed and water depth where the boat passes any particular shoreline site. But, Table 8.3 shows that distance from shore is important in producing the wake in any specific boat pass.

C. Suspended Sediments Resulting from Boat Wakes

Besides measuring wake characteristics in some trial runs, other data were collected at Site C to give a very preliminary idea of the increase in suspended sediment associated with breaking waves in boat wakes along the shoreline. For this experiment, the Uniflite cruiser travelling at a speed of approximately 21 knots made repeated passes 200 ft. offshore, and samples were taken after the breaking of the 1st, 5th, and 10th wake packets. The water in the nearshore was also sampled prior to the passage of the boat and again at the end of all of the passes of the Uniflite cruiser. The samples were collected by immersing one-quart jars about 5 cm. under the water surface immediately after the last wave in each packet broke on the shoreline profiles. The water samples were filtered through pre-weighed 0.6 μm Nuclepore filters. After desiccation, the filters were reweighed to determine total weight of suspended sediments. Then the samples were completely combusted to obtain the percent of organic material.

The results are shown in Table 8.4.

Table 8.4. Suspended Sediment Concentrations

Run	Time	Total Concentrations	Percent Organic
1.) Ambient	1045 EDT	0.0053 grams/liter	35.7
2.) 1st Packet	1125	0.440	20.3
3.) 5th Packet	1127	0.120	21.8
4.) 10th Packet	1130	0.330	23.2
5.) End of Passes	1407	0.081	14.3

Due to a relatively high stage of the tide when the Uniflite runs were conducted, breaking waves extended across the entire foreshore, and the swash impinged against the bank scarp at Site C (Figure 4.17). Table 4.4 shows the foreshore sediments at this site are composed principally of sand with only a few percent of silt and clay. Yet, the data in Table 8.4 show that the breaking waves resulted in an enhancement of the short-term load of suspended material by more than two orders of magnitude over the ambient level.

Inspection of the filters showed most of the material supsended by the boat wakes was clay and silt, but some of the organic material was observed to be buoyant detritus. This increased amount of suspended sediment could come from either the bottom sediments in the nearshore, or from the bank scarp which was within the range of the wake swash. It is interesting to note that once the first boat pass was made, the data show no tendency towards higher or lower concentrations of suspended sediments with an increasing number of boat passes. So this one set of trial runs with the Uniflite cruiser principally demonstrates that boat wakes breaking along the shoreline can increase the short term concentrations of suspended sediments in the nearshore zone at Site C.

IX

DISCUSSION, CONCLUSIONS, AND THOUGHTS FOR MANAGERS

Robert J. Byrne, John D. Boon, III,
Rhonda Waller, and Deborah Blades

A. Discussion

This study presents four lines of evidence which when considered together, provide the basis for inference as to the role of boating activity as a cause of fastland erosion along the tidal shorelines of small coves and creeks. These are:

1.) Direct observation of the fastland and beach changes at five sites in Anne Arundel County over a one-year period.

2.) Estimates of the wind-wave energy throughout the year and that due to boat wakes during the boating season at the five sites.

3.) An inventory of the boating characteristics at five sites reported as having heavy boating traffic.

4.) Field observations at one site of the wave characteristics generated by controlled boat passes at various speeds and distances from the shore.

The purpose of this chapter is to integrate these findings and thereby offer an interpretation of the role boating activity plays in fastland erosion at the tidal shores.

Point 1. Discounting the effects of Tropical Storm David, the direct observation of fastland changes at the five sites (Chapter IV) indicated that only at Site C, in a narrow waterway, was there significant fastland retreat during the boating season. The question naturally arises as to whether comparable behavior of the fastland at the five sites would have been observed in other one-year periods. To address this we must bear in mind that the total erosion response is a combination of that induced by wind waves plus that induced by boat-wake waves. The magnitude of the wind-wave energy will vary somewhat from year to year as a function of gross weather patterns and storm activity. On the other hand there is no reason to assume that the boating activity during the 1979 boating season was atypical of average conditions over recent years. Thus, between years we expect the total wave energy to be a combination of a constant contribution due to boats and a variable contribution due to wind waves.

More directly, the fastland response is dependent upon the frequency of storm activity which may fluctuate considerably from year to year. Observations for a several-year period which includes this variability in storm activity would be required to estimate the "average" erosion response due to the total wave energy. A hypothetical case will illustrate the point. Suppose at a given site boat-wave energy was responsible for a fastland recession of 0.25 ft. every year but because of variation in storm activity the total yearly recession, over a four year period, was 4 ft., 3 ft., 2 ft. and 1 ft. respectively. The yearly percentage of recession due to boat wakes would then be 6, 8, 12, and 25% respectively. Over the four-year period the total recession would be 10 ft. with 10% due to boat-wake energy. Thus in any given year there could be appreciable error in estimating the level of erosion attributable to boat wakes.

In spite of the fact that the observations were conducted for only one year, certain inferences can be drawn about the four sites which showed either no erosion, or where the response during the boating season was very slight. Storm activity during the observation year was relatively slight. No major northeast storms with a strong storm surge occurred (the effects of Tropical Storm David which occurred near the end of the period will be discussed separately). This being the case, the contribution of erosion from boat wakes would be amplified relative to a year with high storm frequency.

Thus the results showing negligible impacts due to boats at four of the sites indicates that, in general, boat wakes play a relatively minor role in the total erosion process at those sites. The same conclusion would apply for sites with similar physiography, bank composition, fetch, and boating activity.

The two sites with bluffs, Sites B and D, warrant special discussion. The principal fastland modification which occurred was slumping in winter and early spring and reduction of that material by wave action. The cause of the slumping action was likely percolation of groundwater, and surface runoff during freeze thaw cycles. By late May much of the material in the slumps had been sujected to wave action and was displaced.

There is no reason to assume that all slumping activity is confined to the winter and spring. Had slumping occurred in early summer then we must assume that the combined wind-wave and boat-wake action would have displaced some of these materials. In such circumstances it would be reasonable to attribute a fraction of the erosion to boat wakes. However, as Table 7.2 indicates, the boat-wake energy appears to be a relatively small percentage of the wind-wave energy (3.6% at Site B and 8.4% at Site D). Such being the case, attribution of erosion to boat wakes would be relatively small.

Point 2. It was previously indicated that only at Site C was there significant fastland retreat during the boating season. Site C, on Broad Creek, is on a narrow channel (600 ft. width) with a relatively steep nearshore gradient. Two of the three profiles showed fastland retreats of 6.8 feet and 5.2 feet (Figure 4.19). Site C received the highest amount of boat-wake energy of the five sites. As well, boat-wake energy accounted for a substantially higher fraction of the total wave energy (Figure 7.7) at Site C than at the other sites.

It is of particular interest to compare Site C and Site B which has a similar nearshore profile, but a wider and shallower channel. The current nautical charts show a MLW depth of 12 feet near Site C and 8 feet near Site B. The two sites received about the same wind-wave energy throughout the year and during the boating season. Site C was exposed to about 5 times more boat-wake energy than Site B. Inspection of the boating characteristics (Table 6.2) shows that the two sites were very similar with respect to average boating frequency, speeds, boat lengths, and hull types. The striking difference between the boating characteristics at the sites is the distance of passage from shore. At Site B, 80% of the boat passes occurred at distances greater than 500 feet, while at Site C 80% occurred at distances <u>less</u> than 200 feet from the shore. These results illustrate the importance of distance of passage in controlling the level of boat-wake energy at the shore.

The physical setting at Site C, the nature of its fastland, and the low sand supply from adjacent fastland are all conditions conducive to erosion in the presence of wave action. The site is a low terrace composed of unconsolidated sand and gravel capped with a very thin marsh. There is evidence that the site is at least partially composed of fill material. More important however, the site represents a transition point where Broad Creek widens, and very little sand is supplied to Site C from the fastland along the shoreline. Thus the erosion of the beach is not inhibited by the addition of sand.

<u>Point 3.</u> The fastland response at Sites B and D to the passage of Tropical Storm <u>David</u> illustrates the relative importance of extreme events in the erosion process of bluffs along tidal shorelines. At Site D the combined

effects of the storm surge (estimated 2.5 ft.), and wave action generated by the southeast wind, resulted in fastland retreat throughout the year including recession of the bluff face itself. However, at Site B, which is more protected from wave action from the southeast, the steep bank showed no response to the storm passage.

B. Conclusions

This study indicates that a significant contribution to the total wave energy (and potential erosion) from boat wakes is likely only when there is a high frequency of boat passages close to shore. While there may be several circumstances wherein boats pass close to shore, the greatest relative impact is likely to occur in narrow creeks where the channel width forces passage within two or three hundred feet from the shore. Since wind-wave activity is likely to be suppressed in narrow creeks, it is under these circumstances that a high frequency of boat passages would generate a large portion of the total wave energy. But it is not likely that further studies at other sites in Anne Arundel County would show boat wakes contribute more energy for erosion than wind waves.

The level of fastland erosion response depends upon the nearshore depth gradient, the composition of the fastland, and the supply of littoral sands from the adjacent shoreline. The conditions most susceptible to erosion would be the combination of an exposed point of land composed of highly-erodible material such as sand and gravel with a steep nearshore gradient. The site which had the greatest change in the shoreline profiles (Site C) possessed all these factors. Experiments with controlled boat passes at Site C indicate that for a given water depth the amount of wave energy generated depends principally upon the boat speeds. At low boat speeds the wake energy is quite small. At intermediate speeds (7 to 10 knots) the wave energy was maximum. At higher speeds the wave energy again decreases. The magnitude of the wave energy as a function of distance was of secondary importance for the conditions tested (50 to 200 ft.). The role of this parameter would be more important at larger distances.

The results of the observations at Site C can be generalized in terms of the Froude Number (proportional to the ratio of boat speed to the square root of water depth). Maximum wave energy occurs in the Froude number range of 0.7 to 1.0 with enhanced wave energy in the range of Froude number values of 1.25 to 1.5 (Figures 8.5, 8.6, 8.9, and 8.10). Inspection of various combinations of boat speeds and water depths (Table 8.3) indicates that a boat speed of 6 knots would generate near-maximum wakes when the water depth is less than 6 feet. A boat speed of 8 knots in water depth ranging between 10 and 4 feet would generate maximum or near-maximum wake. Boats travelling at 4 knots, on the other hand, would not generate their highest wakes except when in water depths of 2 feet or less.

For the range of depths frequently found in narrow creeks fringing the shores of Chesapeake Bay, three particular conclusions may be drawn:

1.) Boats reducing speed to conform to the speed limit pass through the speed range which generates maximum wake.

2.) If the approach to the speed control area is within a narrow creek the shores adjacent to the approach zone will be exposed to the higher wake energies noted in 1.

3.) Boat operators underestimating their speed by only a few knots while in a speed control area could generate a near-maximum wake while transiting the waterway.

C. Thoughts for Managers

Three points which would mitigate the potential erosion impacts due to boats are offered for consideration:

1.) The study shows that depth conditions exist in some creeks wherein maximum boat-wake energies are generated close to the standard 6 knot speed limit. The results can be used to estimate the speeds at which maximum wake is generated for various water depths. In some cases a reduction of the speed limit would decrease the unintentional generation of maximum wake.

2.) Since boats approaching a speed-control zone will pass through the speed which generates maximum wake as they slow from high speed, the speed-limit signs should be placed, when possible, at locations where the creek is so wide that the wake energy can dissipate before reaching the shore.

3.) The study indicates that the greatest potential for erosion impacts due to boat wakes is to be expected when high frequency boat passages occur within a few hundred feet from the shore. Restrictions in such areas would reduce the potential for shore erosion.

D. Recommended Further Studies

The present study indicates that it is in narrow creeks and other circumstances wherein boats pass close to shore that the highest potential for boat-wake erosion exists. The question then naturally arises, "How close to the shore can boats pass without causing the significant wake energy at the shoreline?" The comparison between two sites, one of which showed dramatic erosion during the boating season and the other very little, provides a partial answer. The two sites had similar boating characteristics with respect to frequency, hull sizes, and speed. The only major difference was the distance from shore at which passage occurred. At the Broad Creek site (Site C), where erosion occurred, about 80% of the traffic occurred within 200 feet or less from the shore. In contrast, at the Goose Island site (Site B) about 75% of the boat passes occurred at distances greater than 500 feet. Consequently, the wave energy at Site B was only about 20% of that experienced at the Site C. Thus it appears that passage distances of at least 500 feet are required to appreciably reduce the level of wake energy at the shoreline.

Further observations of controlled boat passes over a wider range of distance from shore would permit a more accurate determination of the creek width necessary for negligible wake energy at the shoreline. The controlled boat passes conducted in the present study covered the range of distances from 50 feet to 200 feet at a single site. This range should be extended to at least 500 feet. In addition other sites with constrasting depth gradients should be added to the data set. As well, the range of hull lengths and types, could be extended.

X

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APPENDIX A

HOUSE JOINT RESOLUTION No. 40

A House Joint Resolution concerning

Anne Arundel County -- Small Creeks and Coves

FOR the purpose of requesting the Department of Natural Resources to design and undertake a study to determine whether continuous high-speed boat traffic is in fact detrimental to small coves and creeks along the Anne Arundel County coastline.

WHEREAS, The Anne Arundel County coastline is highly indented, and the tidal water indentations form shallow, narrow creeks with highly erodible shorelines and fragile biological ecosystems; and

WHEREAS, Continuous high-speed boat traffic may have an injurious effect on the small coves and creeks; now, therefore, be it

RESOLVED BY THE GENERAL ASSEMBLY OF MARYLAND, That starting this year, the Department of Natural Resources is hereby requested to design and undertake a study to determine whether continuous high-speed boat traffic is in fact detrimental to small coves and creeks; and be it further

RESOLVED, That consideration shall be given to closing at least one cove or creek in South, Severn, and Magothy Rivers at all times to vessels operated at a speed in excess of six (6) knots, for such a period as required to facilitate the scientific study; and be it further

RESOLVED, That the Department of Natural Resources shall submit an interim progress report to each member of the House Environmental Matters Committee and the Senate Economic Affairs Committee annually starting 1977, and the report shall be made available to the public. A final report summarizing the results of the study shall be submitted to the General Assembly not later than the 1981 Session, and shall be made available to the public; and be it further

RESOLVED, That copies of this Resolution be sent to The Hon. James B. Coulter, Secretary, Department of Natural Resources, Tawes State Office Building, Annapolis Maryland 21401.

Approved:

Governor.

Speaker of the House of Delegates.

President of the Senate.

APPENDIX B

WIND-GENERATED WAVES

Deborah Blades, Rhonda Waller,
Thomas Burnett, Michael Perry,
Tristina Deitz, Mark Alderson

A. Introduction

This appendix presents a summary of the wind-generated wave heights which were observed at the study sites. These measured wave heights were used to produce site-specific estimates of the wind-wave energy budget during the year-long period of observations. There have been several previous studies of wave generation by winds in shallow coastal waters, (Johnson, 1948, 1950; Kinsman, 1960; Harris, 1972; Seymour, 1977; and Thompson, 1980), and several mathematical models already exist to predict the charateristics of waves (height and period) if the wind speed, duration, and fetch are known. Two examples of these are shown in Figure B.1.

These models are helpful for forecasting general wave conditions in many areas. But, physical oceanographers and mathematicians continue to discuss which

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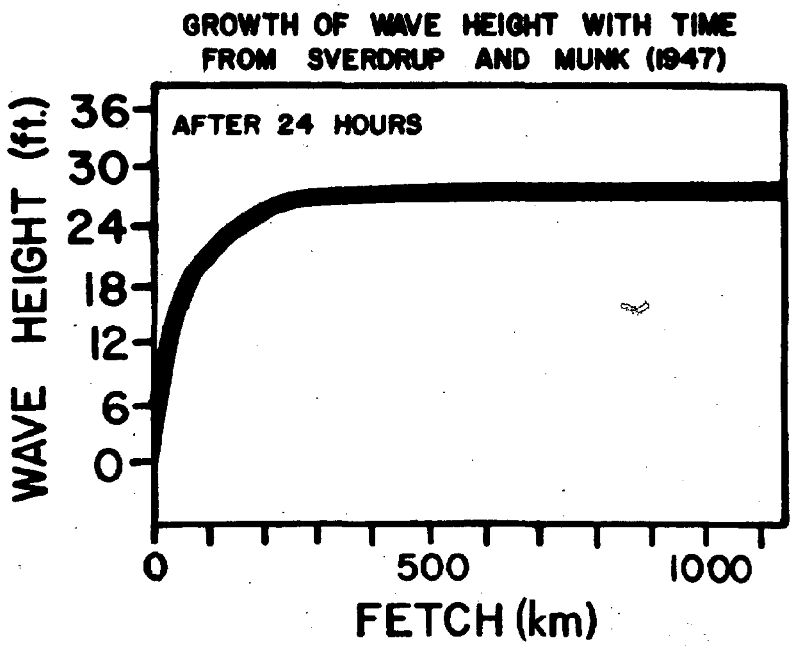
Opposite: Figure B.1 (top) Growth of wave height with time and distance from the upwind edge of a fetch (after Sverdrup and Munk, 1947).

Figure B.1 (bottom) Forecasting curves for shallow water waves in a basin with constant depth equal to 5 feet (from the U.S. Army Corps Shore Protection Manual, 1973).


GROWTH OF WAVE HEIGHT WITH TIME
FROM SVERDRUP AND MUNK (1947)
AFTER 24 HOURS
WAVE HEIGHT (ft.)
36
30
24
18
12
6
0
0
500
1000
FETCH (km)

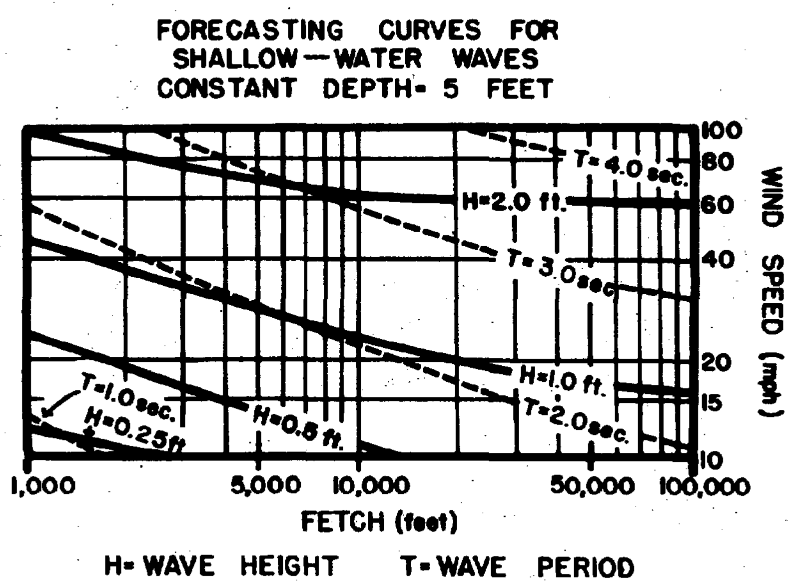

FORECASTING CURVES FOR
SHALLOW — WATER WAVES
CONSTANT DEPTH = 5 FEET
T = 4.0 sec.
H = 2.0 ft.
T = 3.0 sec.
H = 1.0 ft.
T = 2.0 sec.
H = 0.5 ft.
T = 1.0 sec.
H = 0.25 ft
100
80
60
40
20
15
10
WIND SPEED (mph)
1,000
5,000
10,000
50,000
100,000
FETCH (feet)
H = WAVE HEIGHT T = WAVE PERIOD

Figure B.1

theoretical approach should be useful to produce the best description of how waves are generated by the wind blowing across the sea surface (Kinsman, 1965; Plate, et al, 1969; Wu, 1972;). As Figure B.1 suggests, none of the existing information is very useful for predicting the wave heights which could be expected at the study sites described in Chapter IV, since none is particularly sensitive to either the range of basin depth or the range of fetch which are present at the study sites.

In this absence of adequate theoretical models, empirical site-specific wind-wave energy models were constructed by making wave observations at the study sites under different wind conditions. Since wind duration is a factor in wave height, three such models were constructed for each site corresponding to short- medium- and long-duration winds. Monthly budgets of wind-wave energy were then developed for each site from these wind-wave measurements.

B. Methods

Throughout the year of study (October 1978-October 1979), measurements of wave characteristics were made at each of the study sites. These observations included:

- Wave Height - an observer visually measured wave heights at the points where the waves broke in

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opposite: Figure B.2 Portions of the continuous meteorological record collected at the United States Naval Academy gauging station in Annapolis.

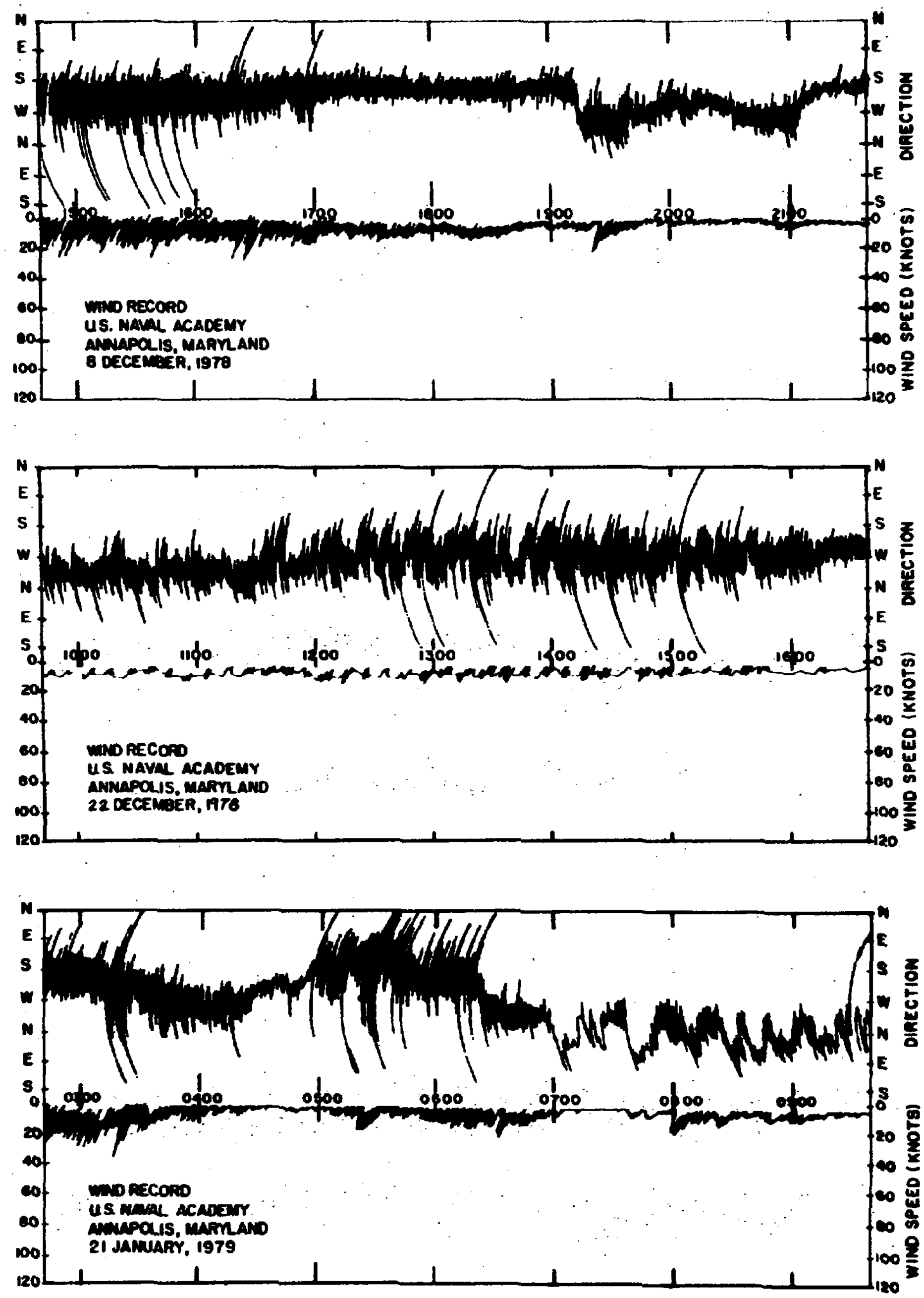
DIRECTION
WIND SPEED (KNOTS)
N
E
S
W
0
20
40
60
80
100
120
1500
1600
1700
1800
1900
2000
2100
WIND RECORD
U.S. NAVAL ACADEMY
ANNAPOLIS, MARYLAND
8 DECEMBER, 1978
1000
1100
1200
1300
1400
1500
1600
WIND RECORD
U.S. NAVAL ACADEMY
ANNAPOLIS, MARYLAND
22 DECEMBER, 1978
0300
0400
0500
0600
0700
0800
0900
WIND RECORD
U.S. NAVAL ACADEMY
ANNAPOLIS, MARYLAND
21 JANUARY, 1979

Figure B.2

nearshore or on the beach using a graduated staff. Munk (1944) has found that the average height of waves so estimated by an observer is about equal to the average height of the 1/3 highest waves. This has been defined as significant wave height.

- o Wave Period - An observer timed 11 successive wave crests with a stop watch. This was repeated three times and the average wave period was calculated.
- o Time of Day - measured with a watch.
- o Wind Speed and Direction - an observer placed a Simms hand-held annemometer (model ss) one meter above the water surface and noted the approximate duration of gusts as well as the dominant wind speed. Wind direction was measured by a compass.

The local wind record that was selected for use was taken from the meteorological station at the U.S. Naval Academy at Annapolis (Figure B.2) which is located within 3 miles, 5.5 miles, 4.6 miles, 1.7 miles, and 6.8 miles of study sites A-E respectively. When the wind velocity at the Naval Academy Gauging Station was compared to the wind velocity at each of the study sites (Table B.1), there were minor differences which are attributable to terrain effects, station separation, and measurement correlation between the

opposite: Table B.1 Comparison of winds at the Naval Academy Gauging Station and at the field sites described in Chapter IV.

Table B.1

SOME COMPARISONS OF WIND MEASUREMENTS

Date	Site	On-Site Wind Description At 1 Meter Above The Water Surface	Naval Academy Gauging Station Hourly Average Wind Speed
March 5, 1980	D	4-5 m/sec gusts to 9 m/sec	6 knots (3 m/sec)
March 5, 1980	A	2-6 m/sec gusts to 9 m/sec	6 knots (3 m/sec)
March 5, 1980	E	5-7 m/sec	8 knots (4 m/sec)
March 5, 1980	D	5-7 m/sec gusts to 10 m/sec	9 knots (4.5 m/sec)
March 10 1980	D	3-5 m/sec gusts 7-10 m/sec	7 knots (3.5 m/sec)
March 10, 1980	A	3-5 m/sec gusts 5-7 m/sec	7 knots (3.5 m/sec)
March 11, 1980	E	1-2 m/sec gusts to 7 m/sec	10 knots (5 m/sec)
March 11, 1980	D	10 m/sec gusts to 13 m/sec	10 knots (5 m/sec)
March 11, 1980	D	10 m/sec gusts to 14 m/sec	8 knots (4 m/sec)
March 11, 1980	E	0 gusts to 4 m/sec	8 knots (4 m/sec)
March 11, 1980	B	4-5 m/sec gusts to 7 m/sec	11 knots (5.5 m/sec)
March 11, 1980	C	4-6 m/sec gusts to 12 m/sec	11 knots (5.5 m/sec)
March 18, 1980	D	7 m/sec gusts to 14 m/sec	12 knots (6 m/sec)
March 18, 1980	E	0-2 m/sec gusts to 5 m/sec	12 knots (6 m/sec)
March 18, 1980	B	3-5 m/sec gusts to 11 m/sec	12 knots (6 m/sec)
March 18, 1980	C	6-7 m/sec gusts to 14 m/sec	12 knots (6 m/sec)
March 18, 1980	A	4-6 m/sec gusts to 10 m/sec	12 knots (6 m/sec)
March 18, 1980	D	7-10 m/sec gusts to 13 m/sec	12 knots (6 m/sec)
March 18, 1980	A	2-4 m/sec gusts to 6 m/sec	12 knots (6 m/sec)

wave height at a particular site and the average hourly wind velocity at the Naval Academy.

The hourly averages of wind speed and direction were visually determined from continuously recording strip charts (Figure B.2). These were compiled to produce the monthly wind roses shown in Figure B.3. This diagram also contains monthly wind roses documenting wind patterns at the Annapolis Naval Academy over a previous 15 year period. The comparison of the two sets of wind roses contains no evidence to suggest the winds in the study year were substantially different from normal, considering that the present study uses hourly averages, and that the 15 year record used two daily instantaneous measurements (probably infrequently collected at night).

The wind rose data for the year of observation shown in Figure B.3 is presented in another form in Figure B.4. This figure indicates the distribution of winds which were used to construct the models of wind-wave energy.

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opposite: Figure B.3 Two sets of monthly wind data collected at Annapolis (obtained from the U.S. Dept. of Commerce, National Climatic Center, Asheville, N.C.).

next pages: Figure B.4 (left) Wind distribution at Annapolis, Md from November 1978 through October, 1979.

Figure B.5 (right) Plots of wave measurements at each of the study sites, presented according to the wind speed and direction measured at the Naval Academy gauging station.

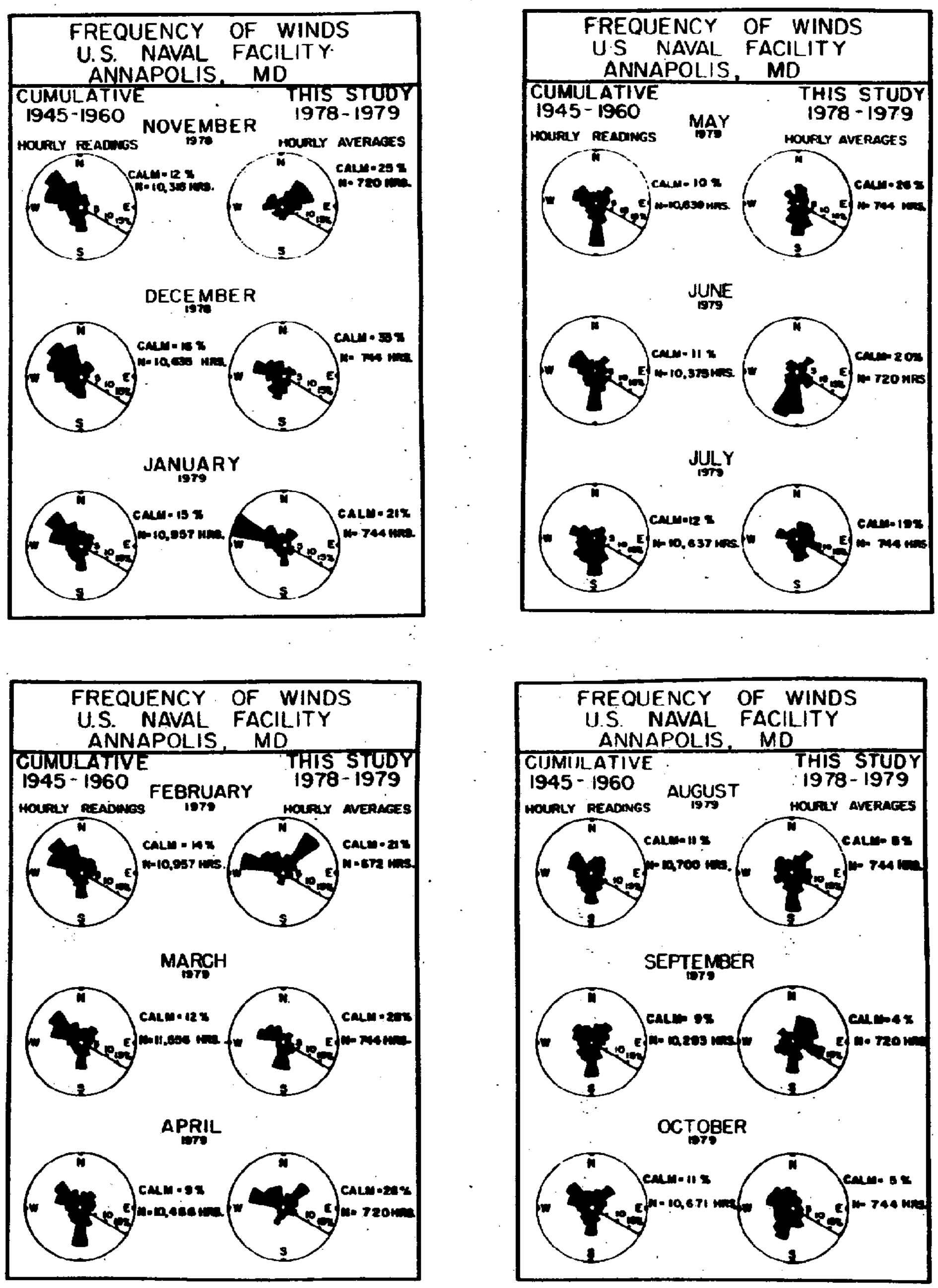
FREQUENCY OF WINDS
U.S. NAVAL FACILITY
ANNAPOLIS, MD
CUMULATIVE
1945-1960
HOURLY READINGS
THIS STUDY
1978-1979
HOURLY AVERAGES
NOVEMBER
1978
CALM=12 %
CALM=25 %
N=720 HRS.
DECEMBER
1978
CALM=16 %
N=744 HRS.
JANUARY
1979
CALM=15 %
N=10,957 HRS.
CALM=21%
N=744 HRS.
FREQUENCY OF WINDS
U.S NAVAL FACILITY
ANNAPOLIS, MD
CUMULATIVE
1945-1960
HOURLY READINGS
THIS STUDY
1978-1979
HOURLY AVERAGES
MAY
1979
CALM=10 %
N=10,630 HRS.
CALM=26 %
N=744 HRS.
JUNE
1979
CALM=11 %
N=10,375 HRS.
N=720 HRS
JULY
1979
CALM=12 %
N=10,637 HRS.
N=744 HRS
FREQUENCY OF WINDS
U.S. NAVAL FACILITY
ANNAPOLIS, MD
CUMULATIVE
1945-1960
HOURLY READINGS
THIS STUDY
1978-1979
HOURLY AVERAGES
FEBRUARY
1979
CALM=14%
N=10,957 HRS.
CALM=21%
N=672 HRS.
MARCH
1979
CALM=12%
CALM=28%
N=744 HRS.
APRIL
1979
CALM=9%
CALM=28%
N=720 HRS.
FREQUENCY OF WINDS
U.S. NAVAL FACILITY
ANNAPOLIS, MD
CUMULATIVE
1945-1960
HOURLY READINGS
THIS STUDY
1978-1979
HOURLY AVERAGES
AUGUST
1979
CALM=11 %
N=10,700 HRS.
N=744 HRS.
SEPTEMBER
1979
CALM=9%
CALM=4 %
N=720 HRS.
OCTOBER
1979
CALM=11 %
N=10,671 HRS.
CALM=5 %
N=744 HRS.

Figure B.3

WINDS AT ANNAPOLIS, MD.
NOVEMBER, 1978—OCTOBER, 1979

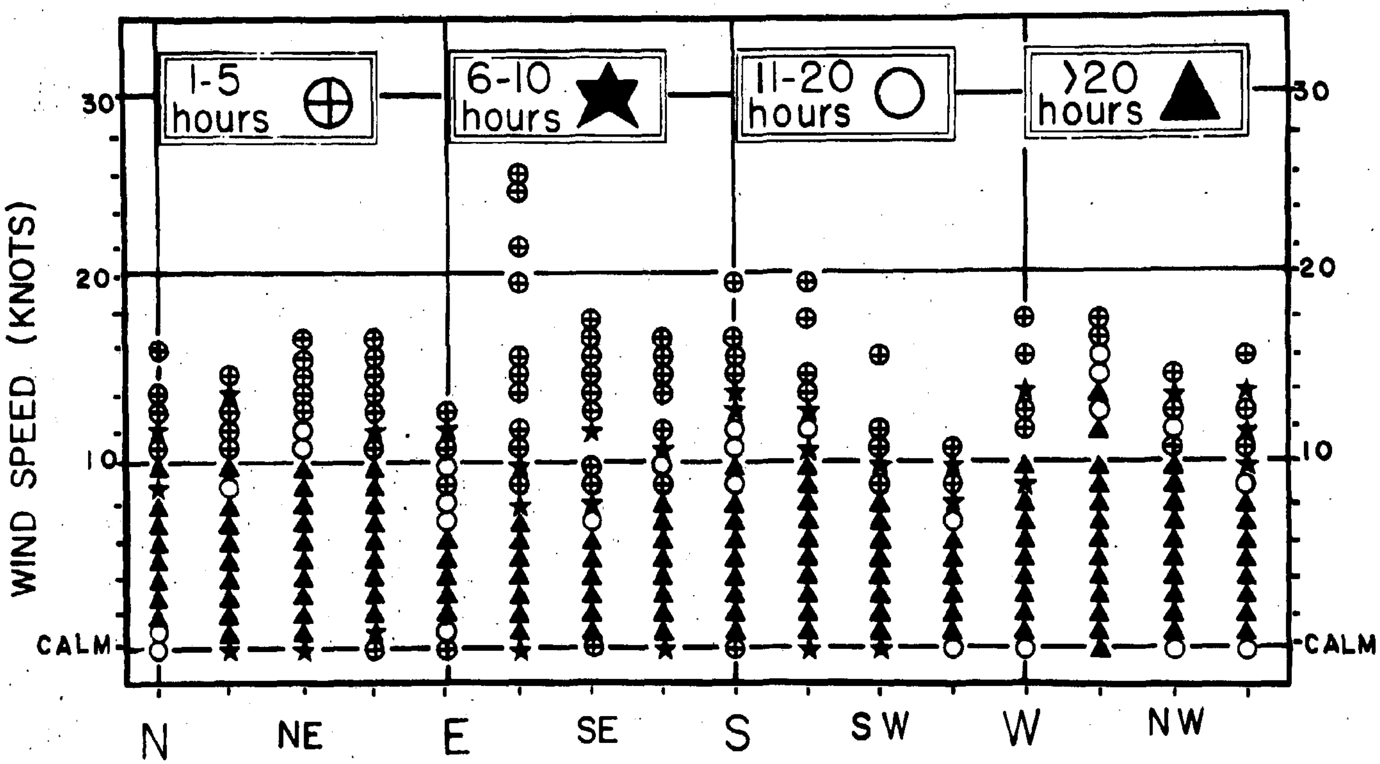

Figure B.4

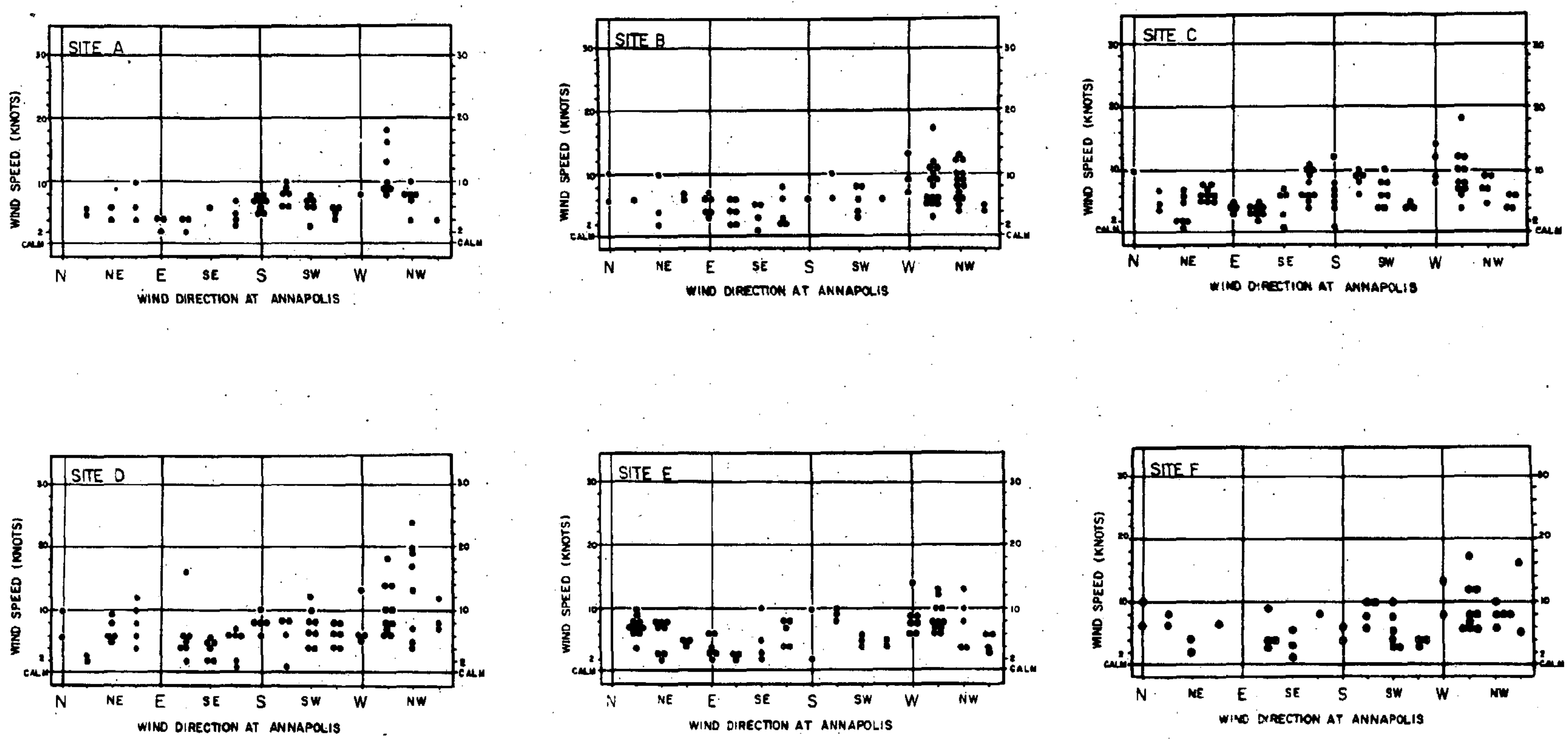
SITE A
SITE B
SITE C
SITE D
SITE E
SITE F
WIND SPEED (KNOTS)
WIND DIRECTION AT ANNAPOLIS
N
NE
E
SE
S
SW
W
NW
30
20
10
2
CALM

Figure B.5

Figure B.5 indicates the range of wind speeds for which on-site measurement of wave heights were collected. This figure shows that few observations were made at the higher wind speeds. As a result, the contours of wave heights at the higher wind speeds in Figure B.6 a-f are shown by dotted lines. These diagrams show the ranges of measured significant wave heights plotted according to the wind conditions recorded at the Annapolis Naval Academy meteorological station. The diagrams also show the fetches at each study site in shaded areas. The site-specific models of wave height are particularly reliable within the range of the most frequent hourly average speeds (0-10 knots).

Three models were prepared for each site for three different velocity durations. The 0-1 hour models were compiled from wave observations collected at times when there was a change in wind velocity greater than 2 knots at the Annapolis Naval Academy gauging station within the hour. The 1-2 hour models were compiled from wave observations collected at times when no change in wind velocity greater than 2 knots occured within the previous two hours. The >2 hour models were compiled from wave observations collected at times when no change in wind velocity greater than 2 knots occurred for more than 2 hours.

C Results

i. Site-specific Models

The largest significant wave heights at each site generally coincide with winds blowing from the directions of greatest fetch. However, at Site B (near Goose Island), the local topography and wave refraction (bending of the wave fronts around irregularities in the shoreline) seem to have influenced the waves so that the largest wave heights were measured when the wind at Annapolis was blowing from a direction with very little fetch at the study site. Site FF located near Site B shows similar behavior in the wind-wave distribution.

Only ripples (wave heights less than 2 cm.) were measured at each study site when the winds at Annapolis were blowing from directions with no fetch. But the diagrams in Figure B.6 a-f show that some wave activity is inferred to be present at the study sites under strong winds greater than 15 knots from these directions of no fetch. It is important to note that Figure B.4 shows there were very few hours of wind speeds higher than 10-15 knots during the year of observations, and many of these hours of higher wind speed were at times when the shoreline sites were covered

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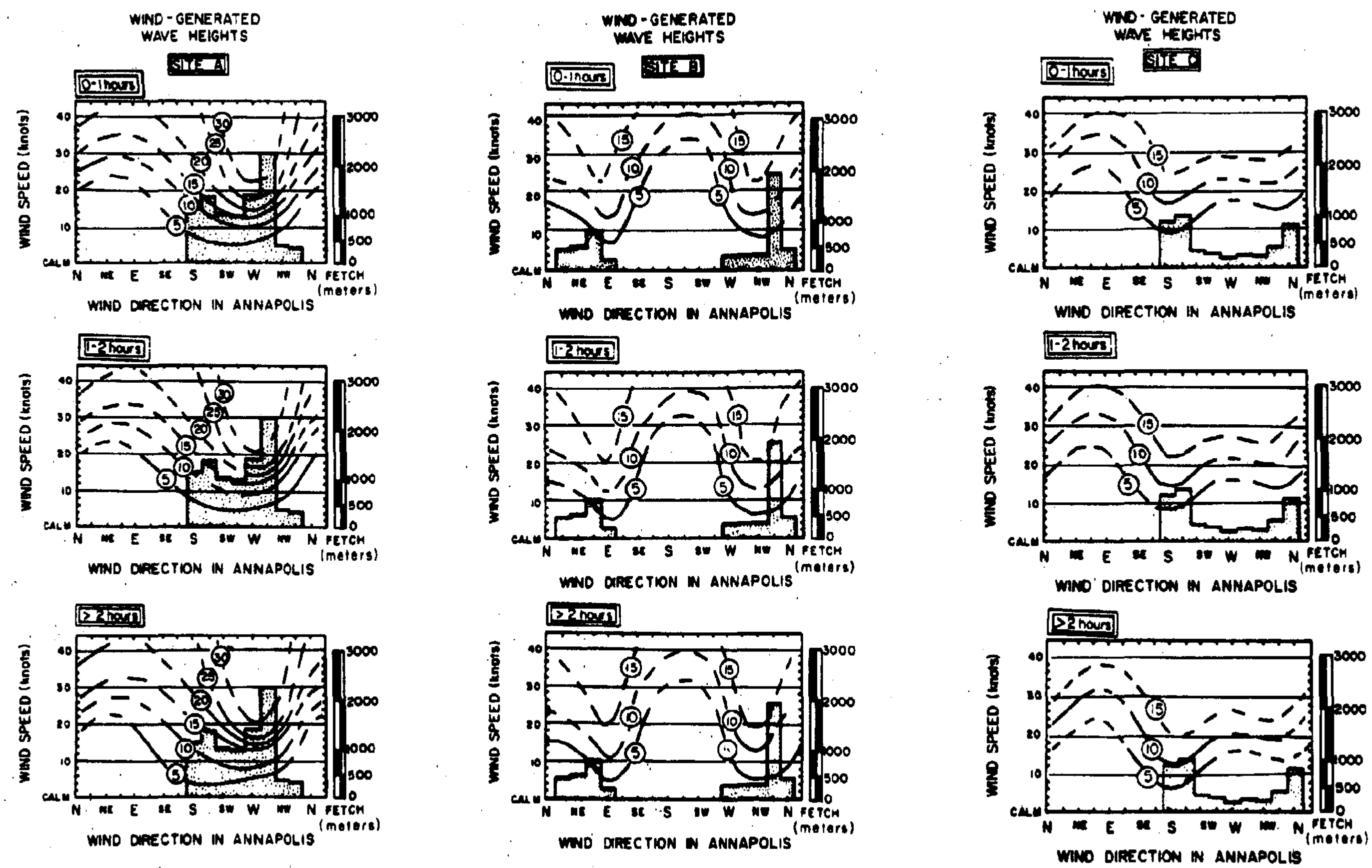
next pages: Figures B.6 a-f Site-specific models of wind-generated waves at each of the five study sites described in Chapter IV. The shaded areas show the distribution of fetch. The wave measurements are plotted according to the wind speed and direction measured at the Annapolis Naval Academy.



WIND-GENERATED WAVE HEIGHTS
SITE A
SITE B
SITE C
0-1hours
1-2hours
>2hours
WIND SPEED (knots)
WIND DIRECTION IN ANNAPOLIS
FETCH (meters)
N NE E SE S SW W NW N
CALM
10
20
30
40
0
500
1000
2000
3000

Figure B.6

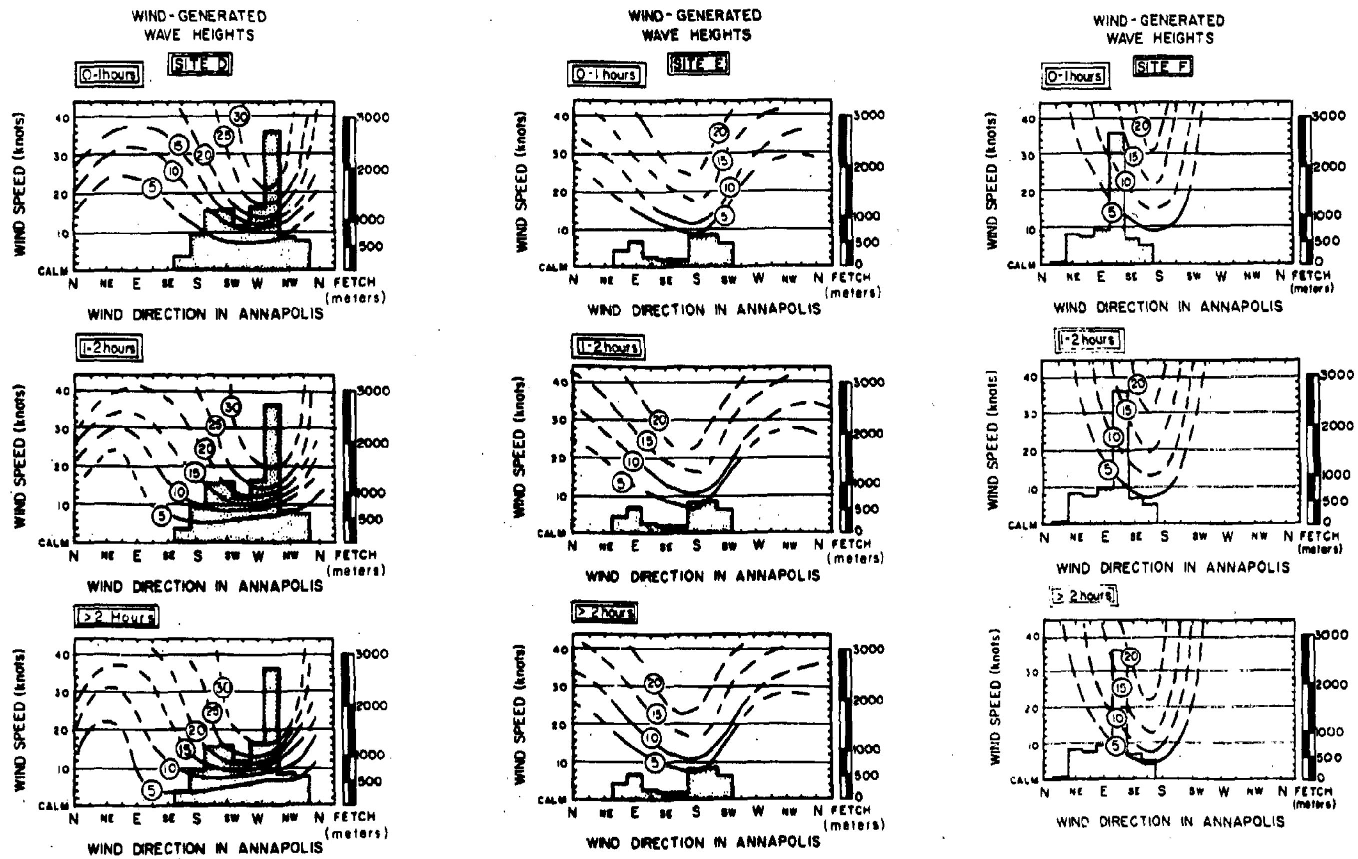

WIND - GENERATED
WAVE HEIGHTS
SITE D
SITE E
SITE F
0-1hours
1-2hours
>2 Hours
>2hours
WIND SPEED (knots)
CALM
N NE E SE S SW W NW N
FETCH
(meters)
3000
2000
1000
500
0
WIND DIRECTION IN ANNAPOLIS

Figure B .6

with ice. So, the inferred distribution of wave heights at these large wind speeds does not have any important effect on the computation of the wind-wave energy budget for this study.

ii. Computation of Wave-Energy Budget

In order to be able to transform wave height into wave energy, the following experiment was conducted. Both the electrical resistance continuous wave height recorder and a graduated staff were used simultaneously to measure wave heights over a range of wave conditions. From the wave recorder strip chart, the RMS wave height was determined for each parcel of waves measured. This in turn was converted into a measure of energy by the equation:

$$E_w = \frac{1}{8} \rho g N H^2_{rms} \qquad \text{B.1}$$

where: E_w = average energy per unit surface area (ft-lbs/ft);

H_{rms} = Root mean square wave height;

$= (\Sigma H_i^2/N)^{1/2}, \; i = 1,2,\ldots,N;$

ρg = Specific gravity of water

$= 62.5 \;\; \text{lbs/ft}^3$

Figure B.7 shows the relationship between observed breaking wave height as measured by the graduated staff, and total energy in the corresponding individual wave packets as measured by the wave recorder. The dotted line in Figure B.7 is the least square polonomial regression line which models the relationship between these two quantities. The equation for this model is:

$$E_w = -2.877 + 3.867\ h - .068\ h^2 \qquad \text{B.2}$$

where: E_w = wave energy (ft-lbs/ft/min)

h = observed wave height in centimeters

The presence of a negative leading term on the right hand side of this equation suggests there is negative wave energy at zero wave height. This spurious result shows the model is approximate, and is a consequence of sampling error and measurement error. In practice, this is of no consequence as all wave heights leading to negative energies were assigned zero energy.

On the basis of the above formula, wave heights at 1 cm. intervals were transformed to wave energies and summed within months. In this manner, monthly wind-wave energy budgets for each of the sites were developed, and are shown in Tables 7.2, 7.3, and Figure 7.7.

iii. <u>Precision of Wave-Energy Estimates</u>

One important question about the wave energy budget is: What is the precision with which the monthly total wind-wave energy is estimated by the above method? The following discussion presents a rough estimate of this precision.

Total Energy "E_h" is the sum over the hours in the month "M" of the energy-per-hour resulting from waves of a given height "h" which were generated by a wind of velocity "V" at Site "S". This can be symbolically represented by:

$$\text{Total Energy}_{M,S} = \sum_{\substack{\text{hours in}\\ \text{month}}} \text{Energy}\,(h(V,S))$$

The relationship h(V,S) is given by the models displayed in Figure B.6 a-f. A relationship between wave energy and wave height is given by the graph in Figure B.7 The variability associated with each hour of estimated wave energy is an accumulation of:

- o the errors in estimating the average hourly wind velocity;
- o the variability in observed wave height for a given wind velocity;
- o the variability in energy per hour as a function of observed wave height.

In the analysis of the study data, the average hourly wind speed on the strip charts was estimated to within ± 1 knot, and the average wind direction was estimated to within ± 22.5°. These magnitudes of error in measuring wind speed and direction typically translate into a wave height error of ± 1 cm. on the wave height models of Figure B.6 a-f. The data from which these wave height models were developed also had typical variabilities which were estimated as follows:

- ± 1 cm. for wave heights measured at wind velocity <5 knots
- ± 2 cm. for wave heights measured at winds between 5 knots and 10 knots
- ± 4 cm. for wave heights measured at winds greater than 10 knots

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opposite: Figure B.7 Observed breaking wave heights plotted against the energy in the waves.

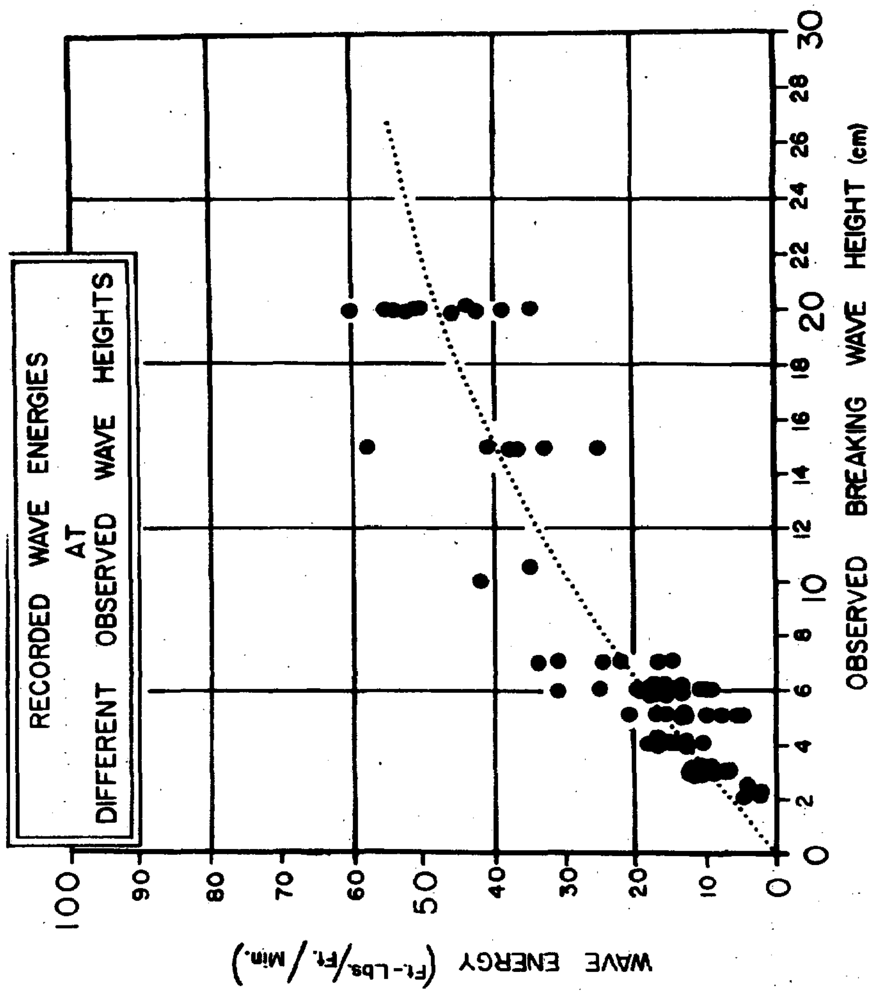
RECORDED WAVE ENERGIES
AT
DIFFERENT OBSERVED WAVE HEIGHTS
WAVE ENERGY (Ft.-Lbs./Ft./Min.)
OBSERVED BREAKING WAVE HEIGHT (cm)
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

Figure B.7

The errors in measuring wave heights and in correlating wave height to wind speed and direction together result in an error in wave height of $\pm$ 2 cm. associated with waves of 5 cm.; an error in wave height of $\pm$ 3 cm. associated with 5-10 cm. waves, and an error in wave height of $\pm$ 5 cm. associated with >10 cm. waves. This variability in wave height translates into a variability in wave energy which is shown in Figure B.7. For example, waves of 5 $\pm$2 cm. have an estimated energy within $\pm$6 ft-lb/ft/min; and waves of 8 $\pm$3 cm. have an estimated energy within $\pm$8 ft-lb/ft/min. For a single value of $\pm$8 ft-lb/ft/min. (equivalent to $\pm$480 ft-lb/ft/hr), there is a standard deviation of 240 ft-lb/ft/hour, assuming $\pm$ 480 represents $\pm$ 2σ. Summing this variability over 720 independent hourly energy estimates for the month gives a total variance of: 720 $(240)^2$ = 41,472,000 ft-lb/ft/month^2 or a standard deviation of 6440 ft-lb/ft/month.

Since total wave energy for any month is typically on the order of 400 000 ft-lb/ft/month (Table 7.3), the error $\pm 2\sigma$ in the calculation of total energy "Eh" by the method described in this chapter yields a precision of 2(6440/400,000). This is equivalent to an error of $\pm$ 3.2%.

This estimate is rough, but it is very unlikely to be off by any factor greater than 2. Even in such a case, the precision of monthly wave-energy estimates are judged to be quite good.

APPENDIX C

SHALLOW WATER WAVE GAUGE

A shallow water wave gauge was constructed by CEA based on a design by McGoldrick (1969). The sensing element of the device is a capacitance probe featuring a loop of Teflon-coated wire (No. 20) mounted on a supporting rod. The Teflon insulation forms the dielectric and the central conductor and conducting fluid surrounding the wire form electrical plates. If the insulation is uniform and end effects are negligible, then the capacitance varies linearly with the proportion of the wire length immersed in the conducting fluid (sea water). A transistorized detector (Figure C.1) converts changes in capacitance into a variable D.C. voltage which is routed to a strip chart recorder (linear model 142). Teflon must be used as the insulating material because of its high resistance to "wetting" by films of water that would otherwise delay the response of the gauge in sensing the rapid fall in water level following the passage of a wave.

The CEA wave gauge is designed primarily for shallow-water applications in small estuaries and creeks. The sensing unit containing the detector and wire loop is a

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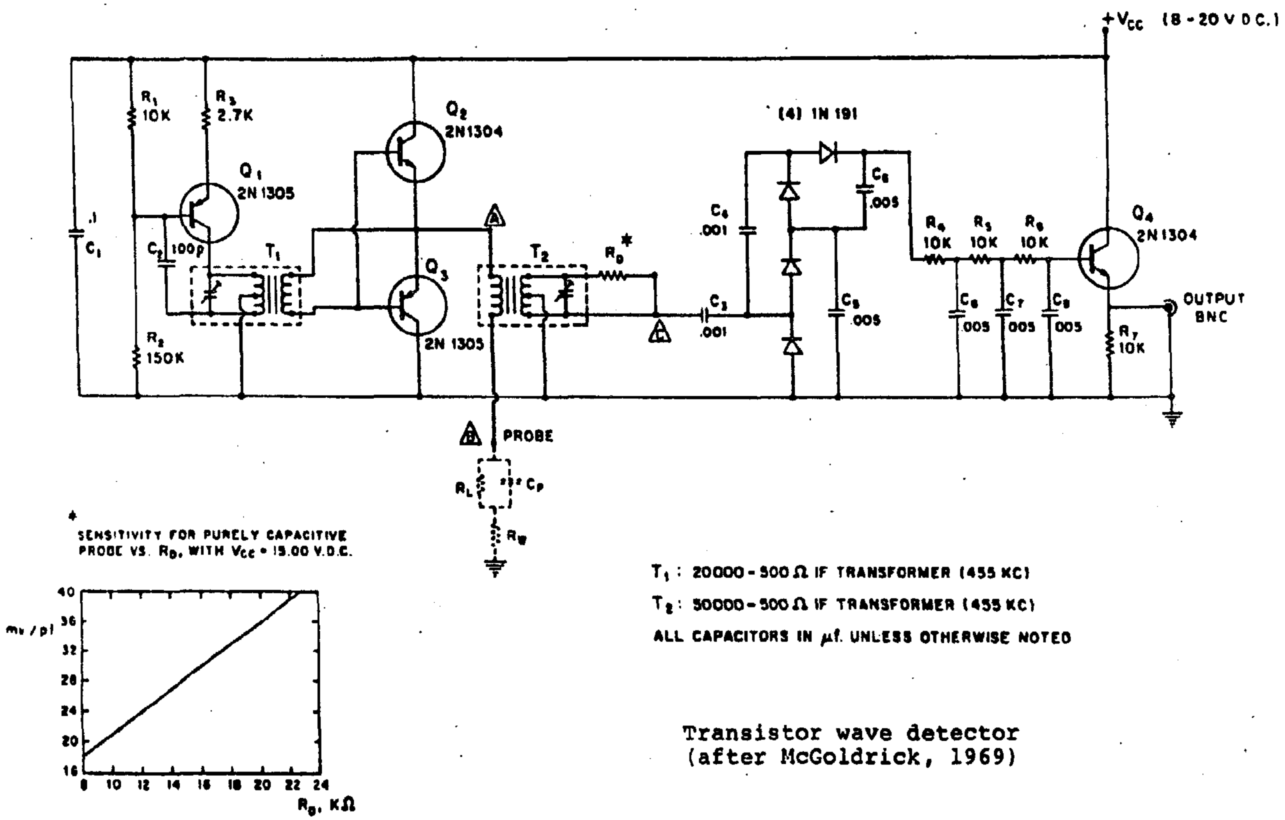
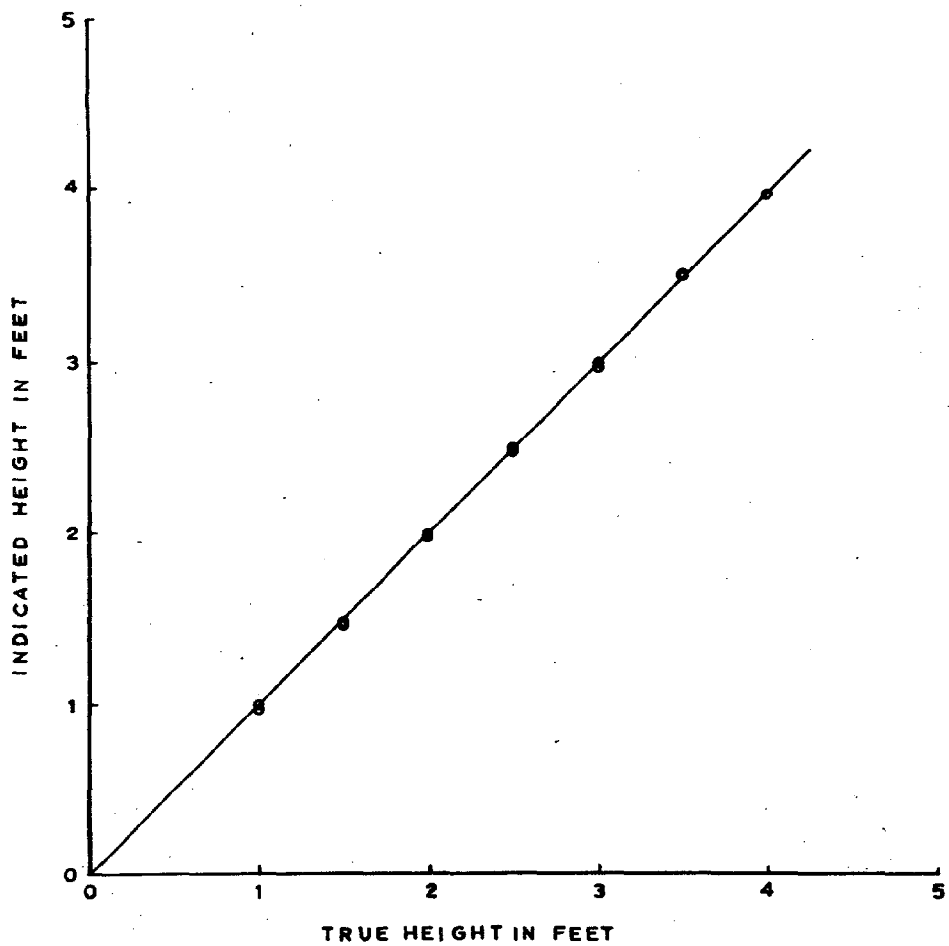
Next pages: Figure C.1. (left) Transistor Wave Detector (after McGoldrick, 1969).

Figure C.2 (right) Wave gauge calibration data.



Transistor wave detector
(after McGoldrick, 1969)

Figure C.1



WAVE GAUGE CALIBRATION DATA

Figure C.2

1-inch diameter PVC rod installed by thrusting its sharpened end into the bottom. A circular footplate mounted 18 inches above the bottom of the rod aids in the installation and provides added stability to the probe in maintaining a vertical position. A 100-foot conductor cable attached just above the foot plate carries the D.C. voltage output of the detector back to the recording unit on shore. The sensing unit can be installed in depths varying between 1 and 3 feet and will sense changes in water level over a vertical range of 4 feet. Markings on the rod at half-foot intervals are provided to allow field calibration checks to be obtained as necessary. Calibration checks should be performed in calm water by holding the probe at 2 or more depths for several seconds and noting the indicated depth intervals on the recorder. Calibration adjustments are made by adjusting the signal attenuation control until the intervals agree.

The detector circuitry is housed in a water-resistant casing at the top of the probe. The unit is activated by means of a switch exposed when the housing cap is removed. Power is supplied by a 9-volt transistor battery located inside the casing. This battery should be replaced after each 50 hours of use. The circuit diagram of the detector unit is presented in Figure C.1.

Laboratory tank calibration tests show excellent linearity in gauge response over the full 4-foot depth range (Figure C.2).